DELHI COLLEGE OF ENGINEERING

LIBRARY

CLASS NO. 621·7

BOOK NO. MAL

ACCESSION NO. 23318

DATE DUE

For each day's delay after the due date a fine of 3 P. per Vol. shall be charged for the first week, and 25 P. per Vol. per day for subsequent days.

Borrower's No.	Date Due	Borrower's No.	Date Due

Plant Layout

PLANNING AND PRACTICE

RANDOLPH W. MALLICK
Executive Staff Engineer
Westinghouse Electric Corporation
East Pittsburgh, Pennsylvania

ARMAND T. GAUDREAU
Management Consultant
Gaudreau, Rimbach and Associates
Pittsburgh, Pennsylvania

New York · JOHN WILEY & SONS, Inc.
London · CHAPMAN & HALL, Ltd.

Copyright, 1951
BY
John Wiley & Sons, Inc.

All Rights Reserved

This book, or any part thereof, must not be reproduced in any form without the written permission of the publishers.

THIRD PRINTING, MARCH, 1954

PRINTED IN THE UNITED STATES OF AMERICA

Preface

"With things investigated, knowledge becomes complete." CONFUCIUS

For industry at large today, only one-half of all labor in a manufacturing plant does the productive work of processing and assembling material into a product. The other half is expense labor engaged in service operations such as receiving, storing, transporting, inspecting, shipping, repairing, and office work. The services of this second group add nothing to the market value of the product and yet cost industry as much as the labor for making the product.

In mechanizing factory operations over the past 100 years, comparatively little attention has been paid to plant service labor. Although improved machinery has succeeded in reducing direct operating cost on the one hand it has given rise to additional service cost on the other. Notable examples are in handling material to and from the new machines, repairing these machines, and new supervision and scheduling necessary to keep these machines operating. Attention has thus far been focused largely on the design of productive machines to the virtual exclusion of the facilities needed to service material to and from these machines.

As a result, much of the high speed and increased capacity available in the processing units in many plants today cannot be utilized because of antiquated arrangements of the plant facilities servicing production. The rearrangement of machinery and equipment to keep material handling and other service costs in line with improved direct costs has become a standing problem in present-day enterprises. Planning rearrangements for existing plants and designing layouts for new plants constitute the engineering functions of plant layout expounded in this book.

Recognition of the growing need for a scientific approach to plant layout problems and design is clearly evidenced in the hundreds of timely articles written on specific applications of plant layout principles in engineering and trade periodicals since World War I. Aside from these publications, extensive research by the authors yielded only sketchy passages on this subject in some books on industrial engineering.

In setting out to cover the unbounded field of plant layout engineering within the confines of one volume, the authors have centered their attention on salient aspects of layout problems encountered in more than 25 years of actual experience in scores of manufacturing plants throughout this country. Extensive assistance was received from leading professional engineering companies and from plants forming a cross-section of practically all important types of industrial enterprise. A partial list of these contributory sources appears under "Acknowledgments" on page vii.

A number of topics deemed connected only remotely with plant layout, or already treated at length in other works, were deliberately omitted. Some of these topics are plant location, building architecture, and construction engineering.

As an aid to quick absorption of subject matter, several sets of elements, factors, principles, and objectives have been presented in itemized lists and tables. Special business forms reproduced in these pages have been gathered from actual applications in several plants.

This book has been written primarily with the administrative executive and plant engineer in mind. It was also developed as a quick guide for senior and junior engineers and as a reference work for engineering colleges and schools of business administration.

R. W. MALLICK
A. T. GAUDREAU

PITTSBURGH, PA.
February, 1951

Acknowledgments

The photographs, drawings, and other illustrative material contained in this book and contributed by professional, industrial, and commercial enterprises are acknowledged in the courtesy lines appearing under the respective cuts and diagrams. The mere presence of a courtesy line falls short, however, of expressing the debt of gratitude the authors owe for the inspiration and encouragement received from these many sources. Space does not permit the individual citation of the industrial executives, professional engineers, shop supervisors, and factory workers who supplied much of the information and experiences described in these pages. Only through the joint contribution of the practical men in the industrial field can a book of this kind be prepared.

Among the firms of professional architects, engineers, and builders who rendered invaluable assistance and guidance, the authors feel particularly indebted to the following: Albert Kahn Associated Architects and Engineers, Detroit; The Austin Company, Cleveland: The M. W. Kellogg Company, New York; Lockwood Greene Engineers, Inc., New York; Stevenson, Jordan & Harrison, Inc., New York; and Stone & Webster Engineering Corporation, Boston.

Especial thanks are also extended to the following manufacturing companies for continued aid and encouragement received during the years the book was in preparation: American Stores Company, Philadelphia; Blaw-Knox Company, Pittsburgh; Dun & Bradstreet, Inc., New York; General Electric Company, several plants; General Motors Corporation, several plants; International Business Machines Corporation, New York; The Lane Company, Altavista, Va.; Standard Register Company, Dayton; Westinghouse Electric Corporation, several plants; Goodyear Tire and Rubber Company, Akron; Harbison-Walker Refractories Company, Pittsburgh; and Philadelphia Electric Company, Philadelphia.

Contents

PART 1. APPROACH TO PLANT LAYOUT

I. THE ROLE OF PLANT LAYOUT IN MANAGEMENT 1

1. Plant layout as the blueprint of management 1
2. Management factors influencing plant planning 2
3. Rearranging or planning a manufacturing plant 5
4. Increased productivity without greater effort 7
5. Position of plant layout in management 10
6. Plant layout organizations in different plants 13
7. Personal aptitudes required in plant layout work 14
8. Qualifications of the plant layout engineer 16

II. ASCERTAINING THE NEED FOR A RE-LAYOUT 20

1. When to consider a change in plant layout 20
2. Revolutionary changes in plant layout design 23
3. Plant layout as a prime factor of production 25
4. The advantages of a good plant layout 27
5. Conditions signifying an improper plant layout 35
6. Prime objectives in contemplating a re-layout 37

III. RANGE OF NEW LAYOUT AND RE-LAYOUT PROJECTS 39

1. Layout stages from job lots to mass production 39
2. The work station as the basic space unit 43
3. The work center inclosing an operating group 45
4. The size and location of plant departments 48
5. Straight-line flow in mass production 49
6. The size pattern of manufacturing plants 55
7. The scope of a plant layout project 57

IV. BASIS FOR DESIGNING A PLANT LAYOUT 60

1. Groundwork preceding the layout development 60
2. Preliminary survey through statistical analysis 62
3. Information gathered for tentative layout plans 63
4. Intangible factors underlying a layout project 66
5. Check lists of advance data for the project 67

V. BENCHMARKS USED IN PLANT LAYOUT WORK 72

1. Plot plans, area diagrams, and process charts 72
2. Records of existing machinery and equipment 80

3. Field notes on buildings and equipment locations 84
4. Spotting machinery and equipment on layouts 86

VI. TECHNIQUES OF PLANT LAYOUT ENGINEERING 90

1. Preliminary template laydowns on layout boards 90
2. Two-dimensional templates for planning layouts 93
3. Scale models for layout projects in miniature 101
4. Procedures for preparing a plant layout 105
5. Perspective drawings and miniature plants 111

PART 2. PLANNING THE PROCESSING DEPARTMENTS

VII. FRAMEWORK OF PLANT LAYOUT PROCEDURE 114

1. Sources and flow of fundamental layout data 115
2. Production data on parts, operations, and machines 116
3. Existing field data on buildings, grounds, and services 117
4. Layouts of existing production facilities and services 118
5. Flow charts of existing and proposed manufacturing methods 120
6. Actual template layouts and operating costs of tentative plans 123
7. Cost information and financial factors for each proposal 124

VIII. DETERMINING THE CAPACITIES FOR THE DESIGN 127

1. Duration and precision of a plant layout design 127
2. Determining the projected output capacity 131
3 Basic factors underlying the output capacity data 133
4. Analysis of performance on the existing layout 135
5. Breakdown of total output into types of products 137
6. Preliminary layout of possible improvements 139
7. The manufacturing program and plant capacity. 144

IX. ANALYZING, BALANCING, AND ROUTING THE OPERATIONS 147

1. Preliminary analysis of the plant layout project 147
2. Operation analysis of manufacturing methods 149
3. Estimates of machine operations and loads 150
4. Determining the labor cost of an operation before final selection 152
5. Final studies of operation time, factory cost, and machine cost 154
6. Functions of process flow charts in routing operations 158

X. PLANNING AND EQUIPPING THE WORK STATION 164

1. Work-station layouts for planning the plant layout 164
2. Methods engineering preceding the design of work stations 167
3. Methods and time study to determine motion economy 168
4. Designing work areas requiring the minimum of motions 170
5. Determining the output capacity of work stations 172
6. Service facilities required within work stations 173

XI. INTERNAL TRANSPORTATION OF PLANT MATERIAL 176

1. Weight, frequency, and travel of material handled in a plant 176
2. Transportation burden on output speed and cost 178
3. Lag in efficiency between material handling and processing 182
4. Classification and application of material-handling equipment 184
5. Factors considered before resorting to material-handling devices 191

XII. PLANNING THE MATERIAL-HANDLING PROJECT 195

1. Analyzing the material-handling requirements for a layout 195
2. Physical aspects of the material and its container 198
3. Building characteristics and safety factors 201
4. Fitting the equipment operations to the volume of activity 205
5. Labor cost, equipment operating cost, and net benefits 208

PART 3. DESIGNING PLANT SERVICE FACILITIES

XIII. RECEIVING, SHIPPING, AND WAREHOUSE AREAS 211

1. Determinants of receiving and shipping areas 211
2. Factors to be considered in a receiving department 214
3. Design of truck- and rail-loading facilities 215
4. Plant expansion within fixed boundary lines 221
5. Warehouse handlings, space, and roof supports 226
6. Multi-story versus single-story warehouses 228

XIV. STOREROOMS AND STORAGE FACILITIES 230

1. Types and functional requirements of storerooms 230
2. Factors for determining storage requirements 234
3. Laying out storage bins, shelving, and racks 238
4. Adjustable and portable racks and bins 242

XV. TEST AREAS, INSPECTION POINTS, AND DISPATCH STATIONS 244

1. Planning for quality control in the layout 244
2. Layout of a receiving-inspection department 246
3. Modernization of laboratories and gauge rooms 249
4. Locating inspection points in the production line 251
5. Planning the general arrangement of a test floor 253
6 Principles of dispatch-station layout design 254

XVI. MAINTENANCE FACILITIES, TOOL CRIBS, AND SPRINKLER SYSTEMS 259

1. Planning the maintenance department and facilities 259
2. Factors in planning and laying out tool cribs 262
3. Provisions for the reconditioning of small tools 265
4. Laying out sprinkler systems and water supplies 267

XVII. POWER AND LIGHTING SYSTEMS 271

1. Outline of factory power-plant operation 271
2. Layout of electric power-distribution systems 273
3. Selection and layout of power-motor drives 282
4. Plant lighting requirements, sources, and circuits 286

XVIII. PLANNING OFFICE LAYOUTS 290

1. Locating the offices and allocating floor areas 290
2. Types of private and general offices in a plant 294
3. Standard specifications for laying out offices 296
4. Basic plans for laying out groups of offices 300
5. Office light, heat, ventilation, and acoustics 303

XIX. EMPLOYEE SERVICE FACILITIES 307

1. Plant approach, parking lots, and plant entrances 307
2. Cafeterias, lunchrooms, and kitchens 311
3. First-aid stations and medical departments 316
4. Locker rooms, water closets, and lavatories 318

PART 4. JUSTIFYING THE LAYOUT PROJECT

XX. BUILDINGS FOR HOUSING THE PLANT LAYOUT 321

1. Plant modernization versus plant construction 321
2. Influence of site limitations on the plant layout 322
3. Blending plant design with creative plant layout 325
4. Shapes and cross-sections of one-story plants 330
5. Column-spacing and clear spans for flexible layouts 334

XXI. CAPITAL OUTLAYS FOR PLANT AND EQUIPMENT 337

1. Amount invested in America's industrial plant 337
2. Distribution of capital expenditures in manufacturing 339
3. Total expenditures for construction and equipment 341
4. Trend of capital outlays for plants and equipment 341
5. Wartime expansion adaptable for peacetime use 347

XXII. PRESENTING THE PROPOSAL TO THE MANAGEMENT 350

1. Prelude to a decision to buy new plant facilities 350
2. Viewing the project on a rendering, model, or layout 352
3. Isolating the proposal on plot and flow plans 357
4. Case presentation of layout proposals for a foundry 359
5. Case development of profits on layout projects 367

Bibliography 373

Index 381

PART 1 · APPROACH TO PLANT LAYOUT

CHAPTER I

The Role of Plant Layout in Management

"By the draught we can find whether the house be sufficient to contain all the works that are necessary to carry on the business." Thomas Ellicott, in *The Young Millwright and Miller's Guide,* by Oliver Evans, Philadelphia, 1795.

1. PLANT LAYOUT AS THE BLUEPRINT OF MANAGEMENT

In simple terms, plant layout is the functional arrangement of machinery and equipment in an existing, or for a contemplated, plant. This general conception is akin to a description of a balance sheet as an accounting statement of the finances of a company. Without a clear understanding of the contents and interrelationship of the various accounts listed on the balance sheet, however, the statement itself has little significance. Likewise, a plant layout drawing is practically meaningless without a sound knowledge of the underlying factors that govern the arrangement shown on the drawing.

Functions of Plant Layout

Plant layout is the master plan that integrates the factory grounds, buildings, floors, departments, machine tools, processing equipment, manufacturing methods, material-handling equipment, service facilities, flow of production, utilization of labor, and shipment of finished products into a unified machine of which management itself is the operator. It is not generally realized that management can be the designer and builder, as well as the operator, of this complex machine.

Because of its comprehensive scope, plant layout is the joint product of the various fields of engineering and management. It is in effect the blueprint that physically co-ordinates the five basic factors of industrial management: men, materials, money, machinery, and markets. In integrating these management factors plant layout becomes the *blueprint of management.* It presents in graphic form the buildings and machinery needed to turn out, within the approved investment expenditure and from the materials specified for the product, the volume of production required for the delivery schedule set by the accepted sales estimate for an established or a contemplated plant.

Focal Point of Management Activities

As the hub from which the enterprise radiates into a unified wheel of industry, plant layout reaches into general administration by determining the economical plant capacity needed to meet sales requirements according to manufacturing specifications. In fixing this capacity, plant layout specifies the justifiable amount of investment in land, buildings, machinery, equipment, and labor force. In the field of manufacturing operations, plant layout directs the flow of work in process and governs the incurrence of labor, fuel, supplies, maintenance, depreciation, taxes, and other factory overhead, all of which constitute the manufacturing cost expended to convert raw material into finished products. In effect, plant layout is the key plan which co-ordinates the management divisions of sales, finance, engineering, production, and accounting into a joint undertaking to yield a net profit to the business. It is the over-all economic pattern of what a manufacturing enterprise can do profitwise with its production facilities in a competitive market.

Definition of Plant Layout

A manufacturing establishment is commonly referred to as a plant, a works, a mill, or a factory, depending upon precedent within the particular industry group to which it belongs and upon the type of manufacturing being done. In this book the word "plant" covers all four of these designations.

As it applies today, a plant layout design may be defined as a floor plan for determining and arranging the desired machinery and equipment of a plant, whether established or contemplated, in the one best place, to permit the quickest flow of material at the lowest cost and with the least amount of handling in processing the product, from the receipt of raw material to the shipment of finished products.

Flow of Materials through a Plant

The material handling planned in the plant layout begins at the receiving point, where the material arrives as raw material, then continues progressively from storage through process, moving in the form of worked material from department to department, from machine to machine, from operation to operation on each machine, and, of particular importance, between the worker and the machine on each operation. In the form of piece parts or worked material, the material flows in and out of temporary storage and is fed through assembly lines for subassembly and final assembly. Provision is made for inspecting, packaging, and storing the material as finished products and for finally loading the products on the shipping platform for shipment to customers.

2. MANAGEMENT FACTORS INFLUENCING PLANT PLANNING

Evolution of a Plant Layout

The analysis of an existing layout or the planning of a new project are fundamentally economic studies embracing product design, market survey, product analysis, sales analysis, time analysis, plant volume, geographic area, productive labor, manufacturing machinery and equipment, material storage, transportation space, tools, inventories, production control, material handling, manufacturing costs, plant site, factory buildings, plant investment, and operating profit. *The planning of a plant is thus something more than the common conception of shuffling templates or scale models on a floor plan.* The successful development of a plant layout entails a succession of ideas and considerations originating in practically all the departments of an organization.

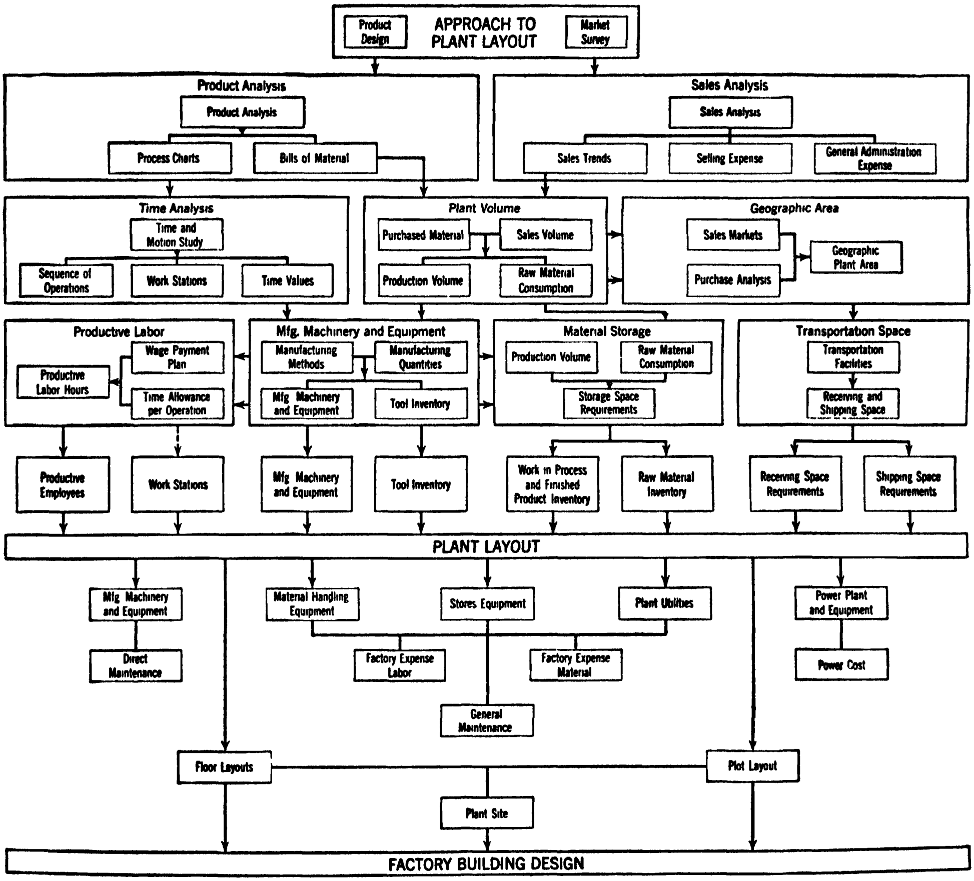


FIG. 1. *Evolution of information for a plant layout.* The various separate sources from which this information is secured and the related sequence in which the data are integrated in process of development.

Because of the broad range of separate management activities affected by plant layout, the ultimate penalty resulting from an improper layout can seldom be wholly identified with any single branch of management, such as engineering or production. The penalty imposed upon an enterprise by an improper layout may escape detection for several years, sometimes not until the management undergoes a reorganization. Then, too, the inefficiency of a layout is naturally not so obvious to the average operating executive as to a trained observer. For this reason, the latent possibilities of improvement are frequently overlooked because of an incorrect or incomplete appraisal of the multiplicity of management factors that influence the plant layout.

From Product Design to Machinery and Equipment

The co-ordination and interdependence of the basic information secured from the various separate sources and the related sequence in which these contributions proceed from one to the other are outlined in Figure 1, the approach to plant layout. At the root of the plant layout are the product design from the engineering department and the market survey of the product from the sales department. The product design supplies the basis for the product analysis in developing process charts and bills of material. From the process charts, time and motion studies are made to determine the sequence of operations, types of work stations, and the time values of the processing operations, which in turn lead to the selection of the proper manufacturing machinery and equipment suitable for the production volume necessary to meet the requirements of the sales volume.

From Market Survey to Machinery and Equipment

The sales volume is in turn determined from the sales trends indicated in the sales analysis made from the market survey, which is the second of the two separate starting points. The evolution from product design to the selection of machinery would thus fall short at this point if it were not co-ordinated with the independent development of the market survey down to production volume.

From Machinery and Equipment to Plant Layout Design

Manufacturing methods form the basis for determining the proper wage payment plan, which, coupled with the time allowance per operation, ascertains the number of productive employees and work stations required in the plant layout. Paralleling this development, the geographic area for the plant, the material storage requirements, and the receiving and shipping space to be provided for in the layout are similarly interrelated and determined. Added to this preliminary information are the sizes of necessary inventories of tools, raw materials, work in process, and finished products. The manufacturing layout proper *does not begin* until all these factors have been carefully weighed and reconciled. The failure to reconcile all these factors *before shuffling templates or models* on the floor plan accounts for the ineffectiveness of many layouts.

Estimating Operating Costs from Plant Layout

The finished plant layout creates the pattern for determining the remainder of manufacturing costs not already reflected in raw material consumption, productive labor hours, and depreciation of machinery and equipment. In creating this pattern, the plant layout positions manufacturing machinery and equipment at definite points along the production line, and thereby makes possible a dependable evaluation of maintenance. In mechanizing certain operations by the use of material-handling equipment, and in selecting stores equipment and planning plant utilities, plant layout supplies the basis for predetermining factory expense labor and material, and general maintenance. Furthermore, by incorporating the power plant and equipment in its plans, plant layout provides a definite basis for power cost.

From Operating Costs to Factory Building Design

Having thus evaluated all operating costs, plant layout is then ready for development into finished floor layouts. These in turn prescribe the size of the factory building or buildings to be designed, and provide the basis for designing a tentative plot plan layout to assist in selecting a suitable plant site. It is at this point that the factory building is designed, for not until the contents of the building have been definitely determined can a suitable building be designed to house the contents.

3. REARRANGING OR PLANNING A MANUFACTURING PLANT

Distinction between Plant Layout and Building Design

Plant layout is not to be confused with building design. In an existing building, plant layout is restricted by structural limitations. In building a new plant, however, the layout can be developed first, and a factory building designed afterwards to house the layout. As a corollary to this precept, the layout itself cannot logically be made until the volume and flow of production have been specifically determined, correlated, and timed.

The particular phase of plant layout that is perhaps the most familiar is the moving of templates and scale models around a floor plan. This function is not only of minor significance but is one of the last steps in layout work. Before moving machinery templates on a floor plan, the quantity and capacity of each type of machine, work station, and inspection point must be calculated. The layout picture itself has but little value unless supported by correlated facts and sound calculations. Of still greater importance to the management is the correct interpretation of the layout picture to permit a joint consideration to be made of the adequacy, economic justification, and preference of the plan.

Planning Plant Layouts from Predetermined Facts

Planning a manufacturing plant or any other producing unit can be and frequently is done with the same scientific degree of precision attained in designing a piece of mechanical equipment. True, the materials and formulas may differ, but the end result—an economic unit for the production of goods—is the same. Just as an engine or a building structure is designed from predetermined facts and relationships, *so a plant layout can be designed from predetermined capacities and characteristics.* This point requires emphasis, for there exist today numerous plants where the production capacities and characteristics are practically unknown to the management. As a result, many of these plants are inefficient production units operating at a loss, giving rise to undetectable management problems. Even more deplorable is the fact that new plants are continually being built with faulty layouts which often doom these plants to inevitable wastes of investment long before production is started.

Machinery is selected to perform certain operations at certain speeds. Operations are based on customer demand and market competition. From the perfunctory gesture of shuffling templates, we have thus backtracked through various departments to find the origin of the need for a plant layout study. When all of the contributing factors have been duly weighed in their logical sequence, it may be discovered even before undertaking to make a layout that a new layout is not needed after all.

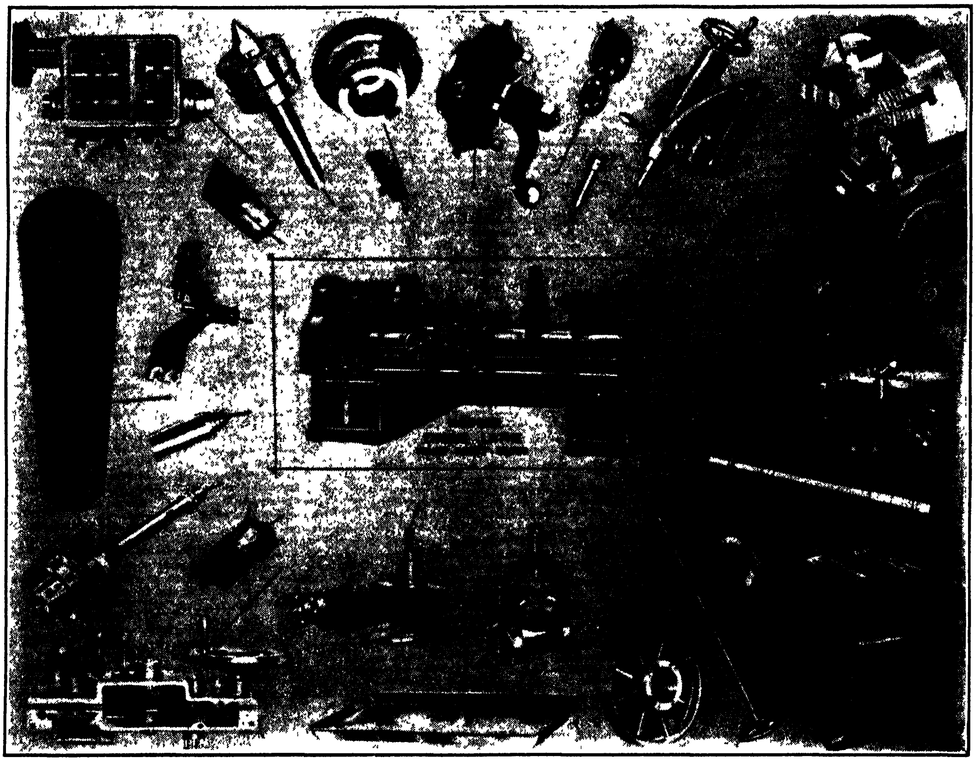


FIG. 2. *Engineering a machine tool.* The quality of this modern engine lathe requires that only the best in sound engineering be incorporated into its design. Do we do as good a job of engineering the plant that will use the machine? (*Courtesy of Gaudreau, Rimbach & Associates, Pittsburgh.*)

Engineering a Machine versus Designing a Plant Layout

Seldom does a far-sighted executive consider engaging other than competent engineering talent to design a new machine or a new product. Yet the same executive often does not hesitate to relegate the layout planning of his plant, worth perhaps a thousand times the cost of that new machine, to the questionable designing ability possessed by foremen, technical clerks, junior engineers, or maintenance supervisors. So deep-rooted is this practice that it is escaping the attention and scrutiny of otherwise efficient management. It marks, in fact, one of the most prolific sources of operating inefficiency, with attendant losses, in American industry today. Figures 2 and 3 contrast the scope of engineering design for an engine lathe valued at $5,000 with the design of a plant valued at one thousand times that amount, namely, $5,000,000.

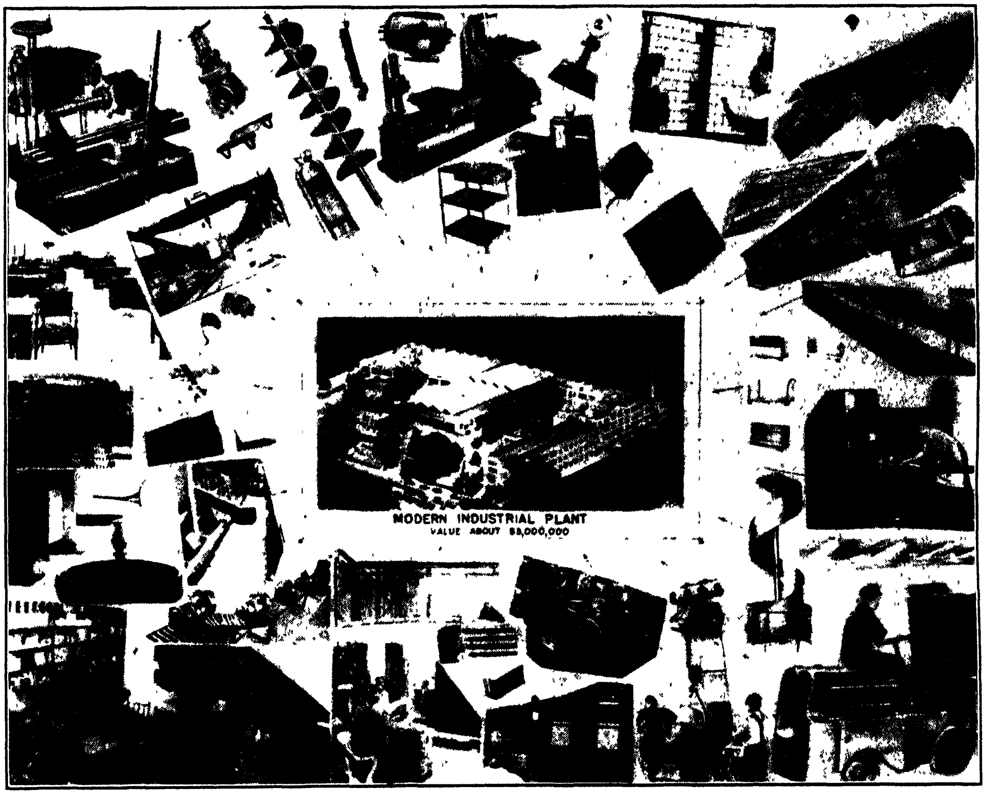


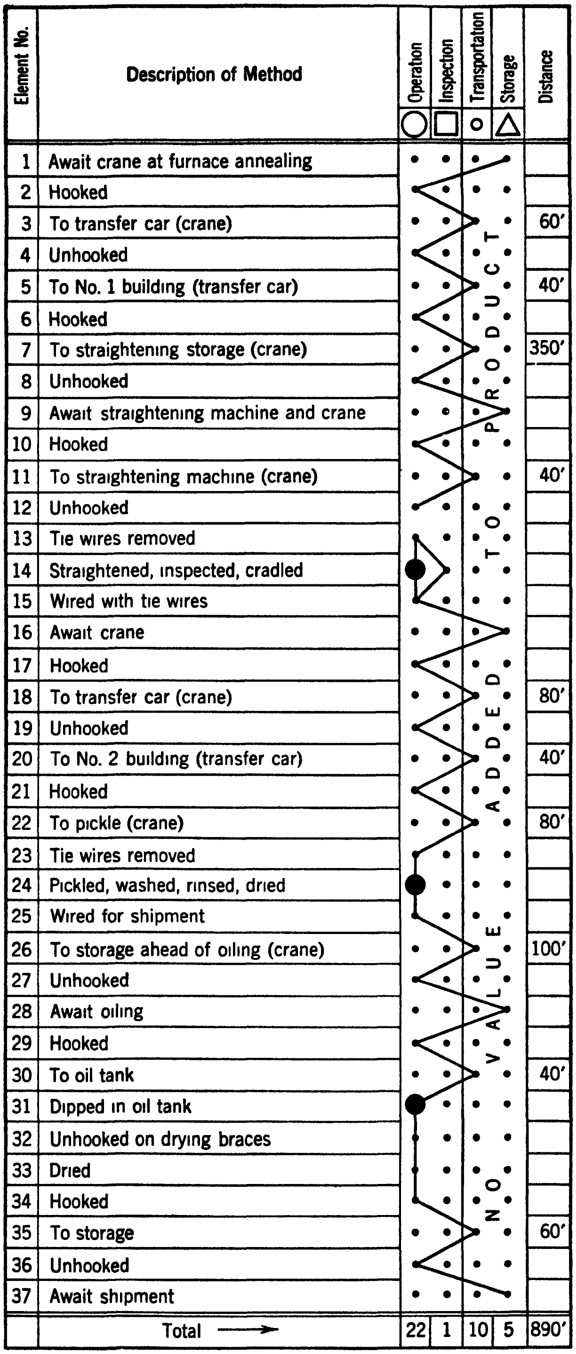
FIG. 3. *Engineering a plant.* Grouped about the photograph of this typical industrial plant are some of the equipment, facilities, and services which, when assembled, make it an efficient production unit. Are we as careful about engineering the whole plant as we are of engineering its detailed parts? (*Courtesy of Gaudreau, Rimbach & Associates, Pittsburgh.*)

4. INCREASED PRODUCTIVITY WITHOUT GREATER EFFORT

Unknown Cost of Material Handling

Recent surveys indicate that the materials in production operations are seldom actually processed, or worked on, for more than 40 percent of the time they are in process, the remainder of the operator's time being devoted to handling the materials at the work station. Just how much money is spent for material handling in a plant is not usually known, as it is not revealed in cost accounts. True, there may be separate shop expense accounts for receiving material, for storerooms, for crane operators, for truckers, for material handlers, for plant transportation, for shipping, etc., covering workers whose entire time is spent on material handling. No account is kept, however, of the amount of time spent by process operators in moving material at their respective stations.

Subject charted: Bar of steel
Chart type: 8" mill rounds
Operation: Strengthen, pickle, and oil
Department: Bar finishing (in a steel mill)


NON VALUE ADDED TO PRODUCT

Element No.	Description of Method	Operation ◯	Inspection □	Transportation o	Storage △	Distance
1	Await crane at furnace annealing	•	•	•	✓	
2	Hooked	✓	•	•	•	
3	To transfer car (crane)	•	•	✓	•	60'
4	Unhooked	✓	•	•	•	
5	To No. 1 building (transfer car)	•	•	✓	•	40'
6	Hooked	✓	•	•	•	
7	To straightening storage (crane)	•	•	✓	•	350'
8	Unhooked	✓	•	•	•	
9	Await straightening machine and crane	•	•	•	✓	
10	Hooked	✓	•	•	•	
11	To straightening machine (crane)	•	•	✓	•	40'
12	Unhooked	✓	•	•	•	
13	Tie wires removed	✓	•	•	•	
14	Straightened, inspected, cradled	●	✓	•	•	
15	Wired with tie wires	✓	•	•	•	
16	Await crane	•	•	•	✓	
17	Hooked	✓	•	•	•	
18	To transfer car (crane)	•	•	✓	•	80'
19	Unhooked	✓	•	•	•	
20	To No. 2 building (transfer car)	•	•	✓	•	40'
21	Hooked	✓	•	•	•	
22	To pickle (crane)	•	•	✓	•	80'
23	Tie wires removed	✓	•	•	•	
24	Pickled, washed, rinsed, dried	●	•	•	•	
25	Wired for shipment	✓	•	•	•	
26	To storage ahead of oiling (crane)	•	•	✓	•	100'
27	Unhooked	✓	•	•	•	
28	Await oiling	•	•	•	✓	
29	Hooked	✓	•	•	•	
30	To oil tank	•	•	✓	•	40'
31	Dipped in oil tank	●	•	•	•	
32	Unhooked on drying braces	✓	•	•	•	
33	Dried	✓	•	•	•	
34	Hooked	✓	•	•	•	
35	To storage	•	•	✓	•	60'
36	Unhooked	✓	•	•	•	
37	Await shipment	•	•	•	✓	
	Total ⟶	22	1	10	5	890'

Fig. 4. *Preponderance of non-productive work elements.* Out of 38 work elements in finish-treating a bar of steel, only 3 (solid black circles) represent actual processing. The remaining 35 elements are considered non-productive and hence an economic drain on costs.

A close approximation of the true labor cost of material handling may readily be made by roughly analyzing the number of minutes per hour each process worker and service employee connected with manufacturing operations spends in actually moving material. To this labor cost must be added supervisory labor, expense supplies consumed incidentally in material handling, repairs to material-handling equipment, and fixed charges on this equipment. Only too often the management has no idea of what the true cost of material handling really adds up to. This cost is buried in total manufacturing cost, and defies detection and analysis.

Material-Handling Cost Hidden in Process Labor

As an illustration of the time spent by process workers in handling materials, a listing is given in Figure 4 of the 38 work elements in finish-treating a bar of steel. Out of the 38 elements, only the following three represent actual processing of the bar:

No. 14. Straightened, etc.
No. 24. Pickled, etc.
No. 31. Dipped.

The remaining 35 elements are considered non-productive. These are summarized below:

Method	Number of Elements
Hooked and unhooked	14
Tie-wired	4
Dried	1
Inspected	1
Transported	10
Stored	5
Total elements	35

In processes requiring a considerable amount of raw material, the true cost of material handling, when known, is usually the largest single item of cost, and it often accounts for 70 percent of the total labor cost. The money expended in handling materials does not add sales value to the product. This economic drain may be attributed to a number of factors, such as improper plant layout, inadequate material-handling systems, and overmechanized processing coupled with undermechanized handling, improper storage facilities, ill-timed production scheduling, etc.

Increase in Output through Better Layout

Scientific layout and routing of material flows had, until World War II, been practically ignored in many enterprises. The savings to be realized from this source were not previously recognized largely because of the lack of a sound approach to plant layout engineering. Increased production through better layout is being attained by reducing wasted labor rather than by making the operator expend more effort. Higher wages and increased productivity without greater effort from the worker are thus made compatible by the reduction of wasted labor in productive operations through scientific plant layout.

The Only Ceiling on Wage Rates

High wages, when actually earned, cease to be high. When a plant is so laid out that wasted labor is held at a minimum, ability to earn is made more readily possible. This ability to earn is the only ceiling on wage rates, but the ability must be made possible by management by periodically rearranging the layout according to more efficient design.

The One Remaining Great Opportunity for Lowering Costs

The fact that the total material-handling cost remains unknown in most plants largely accounts for the lack of realization that material handling offers the one remaining great opportunity for cost reduction within reach today. The possibilities of making a major reduction in manufacturing costs through revising existing plant layouts are virtually untouched in industries outside the meat-packing industry, the automotive, chemical, and food industries, and certain foundries. The role that plant layout plays in increasing productivity, and the unbounded field it opens in reducing costs without disturbing labor rates or sacrificing the quality of the product, while at the same time lessening the worker's effort, forms the subject matter of this text.

5. POSITION OF PLANT LAYOUT IN MANAGEMENT

Layout Data Developed in Methods Engineering

As already pointed out, the finished plant layout design is the joint product of all the divisions of management. Plant layout engineering begins at the point where sales forecasts have been converted into estimated plant output. The plant layout engineer, with the assistance of the methods engineer, analyzes the product into its separate manufacturing operations and expresses these operations in terms of time values on specific types of machines. This analysis indicates the volume and sequence of operations, the quantity of each type of machine needed, and the requisite manpower.

Laying Out Production Flows

With this as a nucleus, the plant layout engineer begins his work of charting production flows, storage spaces, machine locations, material-handling equipment, power supply, etc. No longer are plant buildings determined by merely summarizing the area required for each machine. The plant layout of today is the result of analyzing and co-ordinating all the factors that enter into the design of the layout.

Machinery Selection and Building Design

From the data developed with the methods engineer, the plant layout engineer draws up an itemized list of machinery and equipment needed in the layout plans, and secures purchase and installation costs for these items. The layout plans are then reviewed by the construction engineer, who proceeds to design a building or buildings to the requirements of the floor layouts. The accountant then estimates sales values, cost of sales, and gross profit on the output projected on the proposed plant layouts.

The plant layout engineer specializes primarily in designing production flows and plant arrangement, selecting material-handling equipment, and expressing production plans in terms of capital investment required for the machinery and equipment reflected in the floor layouts. In order to acquire proficiency in his field, the plant layout engineer may devote his lifetime to the study of the functions of plant layout and to the keeping abreast of modern improvements in manufacturing methods, machinery, and equipment.

The Company-Wide Plant Layout Department

Plant layout activities vary in scope and duration in proportion to the size of the plant. Recognition of the importance of assigning competent engineers to plant layout work is evidenced in many large enterprises by the establishment of plant layout departments in individual plants and in company headquarters staff organizations. A specimen functional chart for such a company-wide plant layout organization is shown in Figure 5. The chart divides the headquarters plant layout department into the following five sections: (1) survey section, (2) planning section, (3) field section, (4) layout section, and (5) drafting section. For each section the required type of personnel is given, and the scope of activities is listed. The entire field of plant layout engineering is thus broken down into 73 activities interrelated between five sections of the plant layout department.

Plant Layout and the Plant Engineer

In some plants, the plant layout department reports to the plant engineer. In the larger plants, the plant layout departments report directly to the general manager. This separation arises from the fact that, in the larger organizations, the plant engineer is concerned primarily with construction and maintenance work and is usually too absorbed in these activities to devote enough of his time to the 73 largely specialized activities listed in Figure 5. Another reason is that, on a new project, the work of the plant engineer normally begins at the point where the plant layout engineer's responsibility ends. This line of demarcation overlaps considerably in many organizations, however, depending upon the relative experience and status of the plant layout engineer in charge, or of the magnitude of the plant layout projects on foot.

Outside Consulting Engineers

Where the plant is not large enough to maintain a permanent engineering staff to do layout work, consulting engineers are brought in to develop the layout plans. Consultants are also retained in the larger plants when major construction projects are contemplated or undertaken. In most cases, architects are

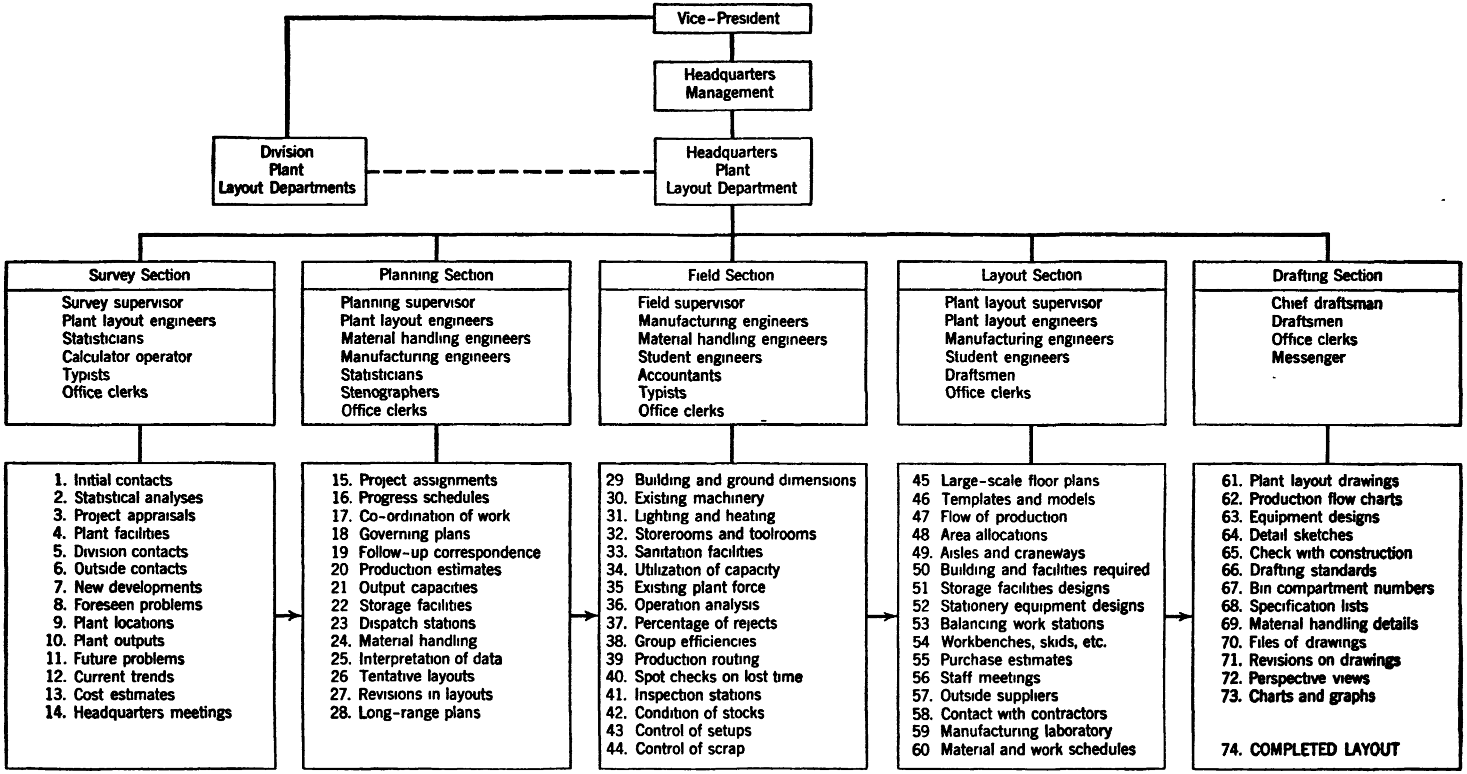


FIG. 5. *Specimen functional chart for a plant layout organization* breaking down the entire field of plant layout engineering into 73 key activities interrelated among 5 sections of the organization.

called in to develop the construction plans. The actual construction work is sometimes performed by the plant forces, but more usually by contractors or by firms of construction engineers. When new plants or additional buildings are constructed, the entire project from planning to actual construction is often undertaken by outside engineering firms.

6. PLANT LAYOUT ORGANIZATIONS IN DIFFERENT PLANTS

Indiscriminate Assignment of Plant Layout Work

Plant layout engineering in many companies has not yet received the recognition of a separate branch of industrial engineering. For this reason, it is not uncommon to find the responsibility for plant layout work intermingled with the duties regularly performed by line organization men, foremen, department supervisors, and shop technical clerks. In other firms, the work is carried on by one or more full-time plant layout engineers and draftsmen. In still other firms, the work is done by consulting engineers, industrial architects, or building contractors. The personnel doing plant layout work in a plant therefore varies with many companies. No standard pattern of plant layout section or department within a plant organization has been developed except in the more advanced or larger establishments.

Variable Status of the Plant Layout Group

In plants that maintain a plant layout group, the personnel in that group is sometimes considered a part of some activity such as the "cost reduction" department or the plant manager's staff. The exact position of the plant layout group of engineers, draftsmen, and clerks in the plant organization has not yet been determined in practice. In some firms, the plant layout activity has attained the distinction of being a separate engineering department on a par with that of product-design engineering, tool engineering, time-study, and process engineering. Plant layout organizations in these companies usually command significant attention and influence in the planning councils of the plant management.

Proper Size of the Plant Layout Group

The size of the plant layout organization, whether designated as a group, a section, or a department, depends primarily upon the nature of the processes, as in continuous manufacturing, or the size of the plant force, as in intermittent manufactures. A large manufacturing company in the metal-trades field, operating widely scattered plants of varying sizes ranging from a plant of 200 employees in a small town up to a concentrated establishment of over 25,000 workers, has developed the following yardstick for determining the proper size of the plant layout staff. This is based on full-time employees to insure the adequate handling of the normal plant layout work at its various plants:

1. For the first 500 employees on the payroll: one engineer capable of supervising temporary assistants.

2. For each additional 1,000 employees: one additional plant layout engineer and one draftsman.
3. For each 10,000 employees: a plant layout consulting engineer on the company payroll. These consultants are usually staff members of the headquarters organization.

For normal, everyday activities, this size of plant layout organization has been found to be satisfactory over a number of years. During periods when projects of a major character are undertaken, temporary personnel are added to the regular plant layout force as needed. On single projects of significant scope, it is not uncommon to find as many as 20 plant layout engineers and draftsmen working at one time, particularly when a time schedule has to be met for the project.

Plant Layout as a Separate Function

Experience has shown that the delegation of the responsibility for plant planning and layout to the head of a staff primarily engaged in some other activity, such as plant engineering or methods engineering, has **seldom produced the desired results.** Plant layout engineering has more and more become recognized as a major function of plant management in the years since 1925. It must be borne in mind that the plant layout integrates all the plant functions into the **master plan of plant operations,** and therefore **should not be subordinated** to any activity which is only a subdivision or component of the enterprise. (See Figure 5.) If a plant is to be kept abreast of modern developments in machine design, material-handling equipment, and the economical flow of work, the plant layout function can no longer be shifted around among line supervisors or junior executives as a matter of passing importance.

Plant layout is a recurrent and ever-present problem of decisive influence on plant operations. For this and other reasons already advanced, the responsibility for recognizing and solving plant layout problems calls for management engineering talent of the highest order, from the standpoints of technical knowledge and ability, to visualize operating advantages from the scientific arrangement of plant facilities.

7. PERSONAL APTITUDES REQUIRED IN PLANT LAYOUT WORK

Personnel Pitfalls in Plant Layout Work

In companies where a plant layout section or department is maintained as a part of the regular organization, the personnel making up the plant layout group are usually selected on the basis of certain special qualifications required for the proper performance of plant layout. Many a good plant layout plan has never gotten beyond the drafting table because of the lack of certain personal characteristics and aptitudes on the part of the plant layout engineers who developed the plan.

The labor force may have resented the engineers' tactics in developing the plan and, as a result, raised objections which would have made the layout unworkable. Or the planning engineers may have failed to enlist the support of some foremen, supervisors, department heads, process engineers, maintenance engineers, etc., to the point where their concerted resistance to the plan doomed its acceptance by the management. Lastly, and perhaps of most frequent occurrence, the presentation of the plan to the management for approval may have failed to bring out clearly the true economic justification of the proposal. Engineers are proverbially deficient in knowledge of the economic aspects of a manufacturing project, be it plant layout, product design, selection of machinery, operating costs, or capital outlays for plant and equipment.

Personal Characteristics Required

To guard against the waste of cost and effort in designing plant layouts that fail to gain acceptance because of improper co-ordination of effort or lack of clear perspective from a management standpoint, certain characteristics and specialized abilities are customarily sought in candidates considered for plant layout engineering work. The principal qualifications most commonly considered as requisites in the make-up of a plant layout engineer are enumerated below. Not all these qualifications are expected to be found in any single individual, but enough of them should be possessed by various members of the plant layout group so that the aggregate of all individual qualifications covers the major portion of the list that follows.

PERSONAL CHARACTERISTICS REQUIRED IN PLANT LAYOUT ENGINEERS

1. **Analytical mind.** Ability to analyze a product into its manufacturing operations, and break down the operations into their motion elements. When several products, each with its own set of operations, are involved, it takes a "master of detail" to wade through the inevitable maze of figures on quantities, time values, and machine loads without becoming inextricably entangled.
2. **Vision.** Faculty to visualize mentally, in advance of drawing up plans, the detail functions of the contemplated layout. The engineer's imagination should be capable of perceiving a complete work station, the motions of the operator at the nebulous work station, the flow of material between work stations, the stoppage points of work in process, and the functions and scope of the contemplated storerooms, toolrooms, and service facilities.
3. **Personality.** Ability to get along with people in all levels of the organization, and to question people without antagonizing them. This ability to win cooperation is recognized as the most valuable asset in any person's make-up, and a marked degree of this quality is manifestly indispensable in approaching the labor force, contacting supervisors and department heads, and reporting findings to the management in the form of recommendations.
4. **Leadership.** Knack of drawing people into the project and of making them feel that they are contributing to the formulation of the plans. With this sense of being a party to the project, the co-operative support of co-workers in securing management approval of the plan and in making the installation afterwards is invariably obtained in a measure that usually guarantees the operating success, if not the economic wisdom, of the undertaking.
5. **Salesmanship.** Ability to convey clearly to the management the relative merits of the proposed layout. The presentation of the proposal entails considerations of

operating costs, capital outlays, various alternatives, economic projections, return on investment, etc., which combine to justify or condemn the project. In order to be able to convince the management of the relative merits of the layout in these terms, the layout engineer must not only be familiar with the nature of these aspects but must be able to write and discuss these considerations without difficulty.

8. QUALIFICATIONS OF THE PLANT LAYOUT ENGINEER

Variations in Duties of Plant Layout Engineers

The duties and responsibilities of a plant layout engineer vary in scope, although not necessarily in type, with the size of the project he happens to be developing. For a minor plant layout job, such as revising a work station or a small group of operations, he may perform all the duties from making detail drawings of existing arrangements to the final development of the finished relayout.

His duties will vary also with the size and type of the plant organization. In a small organization where he spends only a part of his time on plant layout work, being occupied otherwise perhaps as plant engineer, he will delegate most of the plant layout work to one or two draftsmen and will confine his layout attention to the supervision of these men.

Consequently, this type of plant layout work is of necessity centered on the drafting board. In larger plants, where plant layout engineers work as such on a full-time basis, the duties and responsibilities of a plant layout engineer are largely standardized and prescribed. In this case, the plant layout engineer must be capable of laying out a complete project ranging in size from a single work station to the development of an entire new plant.

Technical Qualifications Required

To qualify as a full-time plant layout engineer capable of successfully discharging the duties and of independently carrying out the responsibilities of this position, the following background of education and experience, coupled with the analytical characteristics indicated, is a desirable asset. Some engineers possess many of these qualifications to a satisfactory degree, but seldom are they all found in high degree in any one individual. It is necessary, therefore, to seek a candidate equipped with the largest measure of the requirements enumerated below:

1. A sound knowledge of the basic sciences of physics, chemistry, mathematics, mechanics, cost accounting, and business management, plus a close familiarity with the principles of mechanical and architectural drawing.
2. A working knowledge of time and motion study, manufacturing processes, operation analysis, production control, and the functions of industrial plant organizations. Actual operating experience in the plant is particularly desirable.

3. Ability to develop co-ordinated plant layouts ranging in scope from a single work station to a complete plant. This function entails the supporting capability to determine accurately the floor space, quantity of processing equipment, type of material-handling equipment, and extent of transportation facilities, plant services, and auxiliaries required for a complete project.
4. Sufficient knowledge of industrial building design and construction to be able to develop layouts that are practical from a construction standpoint and are in conformance with standard building codes.
5. Sufficient knowledge of mechanical and electrical engineering principles to be able to develop preliminary layouts for plant services and utilities.
6. Ability to analyze thoroughly the material-handling and storage requirements for a project and to design or specify facilities for these requirements.
7. Analytical ability to develop a number of alternative plans and to weigh their relative merits before presenting the final proposal to management.

Principal Functions of the Plant Layout Engineer

When the plant layout engineer is on a project or in an organization where he has assistants under him, or where assistants are available as needed, many of his functions can be delegated to these subordinates. In Table 1 are listed the 23 principal functions of the plant layout engineer and the portions of these functions which may be delegated to detail engineers, project draftsmen, and detail draftsmen assigned to plant layout work.

Draftsmen's Activities

The first seven functions, dealing principally with making drawings, taking field notes, and preparing flow charts, etc., are assigned to **detail draftsmen,** although some of these functions are also delegated to **project draftsmen.** In addition to these detail duties, the project draftsmen also function as instructors to junior draftsmen and are expected to be able to prepare the plans for a complete project and to design material-handling and storage facilities.

Duties of Detail and Project Engineers

The **detail engineer** comes in at this point and, besides sharing some of the project draftsman's work, holds the responsibility for analyzing all engineering data concerning products, time studies, production, quality control, and plant facilities, and for developing the plant layout in template or model form. The remaining eight functions of plant layout work are reserved for the plant layout **project engineer.** Upon him rests the responsibility of developing complete layouts, preparing building specifications when needed, imparting engineering knowledge to subordinates, surveying the facilities and capacities, and contacting the personnel in various other departments, such as sales, production, time study, accounting, etc., for information concerning the projects.

TABLE 1. PRINCIPAL FUNCTIONS OF PLANT LAYOUT PERSONNEL

Function Number	QUALIFICATIONS AND RESPONSIBILITIES (X in right-hand columns denotes personnel responsible for each function listed below.)	CLASSIFICATIONS OF PLANT LAYOUT PERSONNEL *			
		Draftsmen		Engineers	
		Detail Draftsman	Project Draftsman	Detail Engineer	Project Engineer
	Make neat and accurate detail working drawings of:				
1	*a.* Building floor plans for a factory department.	X			
2	*b.* Arrangements of machinery and equipment.	X			
3	*c.* Renderings of existing and proposed plant facilities.	X			
4	Take field notes that can be used by other co-workers.	X	X		
5	Prepare flow charts, diagrams, and schematic sketches.	X	X		
6	Use and interpret building codes of standard practices.	X	X	X	X
7	Adopt and follow the company's standard drafting practice.	X	X	X	X
8	Instruct and direct junior draftsmen in taking field notes.		X		
9	Instruct and direct draftsmen in technical phases of the work.		X	X	X
10	Draw a complete project of existing or new plant facilities, including service areas and ground improvements.		X	X	
11	Devise and design material-handling and storage facilities in complete detail.		X	X	X
	Interpret, prepare, compile, and analyze engineering data:				
12	*a.* On products, existing or new.			X	
13	*b.* From time study, production, and quality control.			X	
14	*c.* On equipment, buildings, and plant facilities.			X	
15	Develop plant layout arrangements in template or model form.			X	
16	Develop complete plant layouts for an entire project, covering the manufacturing and service facilities, grounds, and ground improvements.				X
17	Prepare specifications for architects and contractors.				X
18	Impart engineering information to design draftsmen.			X	X
19	Survey the manufacturing facilities and capacities.				X
20	Prepare construction requirement schedules for the project.			X	X
	Prepare, maintain, interpret, or supervise others in:				
21	*a.* The establishment of complete project records.				X
22	*b.* The translation of field notes into reproduced plans and records of existing facilities.				X
23	Co-ordinate the plant layout work on the project with the personnel in the works engineering, sales, production, time study, process engineering, accounting, and factory departments to assure the procurement of correct and accurate source information and records and of the true objectives of the project.				X

* In plant layout departments consisting of more than one person, the duties of the plant layout engineer may be delegated to detail engineers and draftsmen. The duties of each of these men may be overlapped, as needed, depending on individual qualifications and capabilities possessed by the personnel.

Responsibilities of the Plant Layout Supervisor

In some plants where the size of the plant layout department permits it, a **plant layout supervisor** is in charge of all plant layout activities. This supervisor devotes the greater portion of his time to directing the work on the various projects being developed and to contacting the various plant and office departments outside his own. Another major function of the supervisor is to prepare and make the presentation of the completed proposal to top management. When the project is later installed, the plant layout supervisor is often called upon to co-ordinate the work of the building architects and contractors toward the fulfillment of the objectives of the layout.

CHAPTER II

Ascertaining the Need for a Re-Layout

1. WHEN TO CONSIDER A CHANGE IN PLANT LAYOUT

Mushroom Growth into Improper Layouts

A large manufacturing establishment is almost always the outgrowth of additions made to existing buildings. As a business expands, new bays are constructed adjacent to existing ones, a roof placed over them, and the completed offshoot sometimes designated as another building. Plants which have been expanding piecemeal over a period of years without paying much attention to the over-all arrangement are today confronted with the necessity of competing with the lower production costs being enjoyed at other plants where the advantages of an integrated plant layout have already been introduced.

In many industries today, despite our much-vaunted mechanical age, there is more labor cost incurred in picking up material, laying it down, feeding it into machines, transporting it in the plant, storing it, and handling it in general, than there is in actual processing or fabricating. Inadequate plant capacities, excessive plant investments, or costly operating conditions within a plant, all due to improper plant layout, are fixed impediments to profitable plant operations.

First Signs of an Improper Layout

The need for a change in plant layout is usually first reflected in unfavorable costs. It may also arise from the introduction of new products, or become evident from a change in the market demand, either up or down, for the existing products. More usually, however, bottlenecks in the flow of production are brought up by the production department for possible solution through a rearrangement of machinery and equipment. Preliminary indications of the need for a rearrangement of equipment are often based upon visible effects rather than upon underlying causes, the remedying of which latter source might dispense with the apparent need of a change in layout.

Why Product Costs Appear High

When profits are good, the tendency is to increase plant capacity in order to secure more of the good profits. When profits are low, on the other hand, or when the enterprise is operating at a loss, the tendency then is to overlook plant capacity and to clamor about high costs. But what is it that makes costs appear high? Obviously it is the low profit or operating loss being realized by the enterprise. But do high costs automatically disappear when profits are good? When all the facts are known, the plant that has high costs in periods of low operating profit has equally high costs, often higher, in prosperous times, with a given plant layout.

Material and labor costs are high only when improperly incurred. The selling price of the product has little, if any, direct relationship to high costs because sales income does not regulate the degree to which cost outgo is utilized. The sales price of a finished product normally influences the quality put into the product, but it does not necessarily govern the amount of unwarranted or wasted labor, material, or operating expense incurred in factory operations. Such unwarranted waste is occasioned largely by the improper layout of the plant.

Keeping Layouts Abreast of Business Changes

Management is the unseen force that drives all plant operations. The true test of the efficacy of an industrial organization is its ability to adjust its production facilities to the changing conditions of business and to forever look beyond methods inherited from the past. Plant layout requirements are constantly changing, for without change there can be no progress. Periodical expansion and inevitable changes in product eventually make the best laid out plant obsolete unless the layout is kept apace with business changes. When a plant fails to make the required layout changes from time to time, it usually finds itself confronted with the need of a complete reorganization plan. By continually challenging the arrangement of its plant facilities, top management is able to take advantage of all new improvements in operations as they arise.

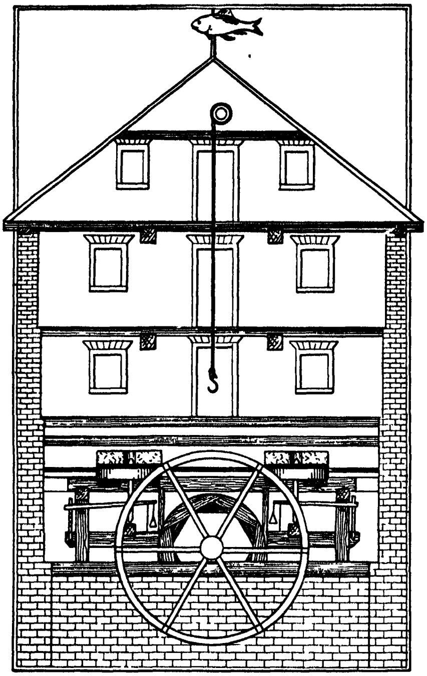
Plant Planning Never Ceases

Planning the capacity of a plant is a continual problem for top management, and it varies in form as time moves on. The problem may arise from adding new products, new sales outlets, new equipment, new employees, new departments, new processes, or new safety measures, or it may arise from a retrenchment of activities. Whether the change involves $500 or $5,000,000, it requires systematic planning and execution. In some plants the layout of machinery and equipment is a matter that is taken for granted. To consider a rearrangement of floor layouts in such plants is almost tantamount to sheer demolition of existing manufacturing facilities. Many manufacturing establishments are the outgrowth of additions made to existing buildings in which the layout has remained fixed for generations. In such plants the notion prevails that the only time to consider a layout is while the plant is being constructed. In other plants the layout is in a continual state of flux because the planning is unsound.

Initial Barometers of the Need for a Re-Layout

Somewhere between these two extremes there exists a firm basis for detecting the need for a change in plant layout and for ascertaining its economic justification. The undertaking of a layout project may be compared to the setting up of a business venture. They are both measurable in terms of sales, cost, and gross profit, no matter how large or small the layout project or the business

Plate XXI.

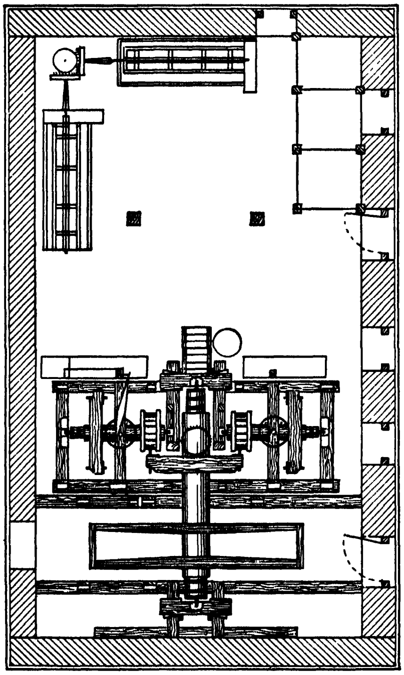


Cross-sectional elevation

Description of Second Floor Laid Out on Plate XIX Below

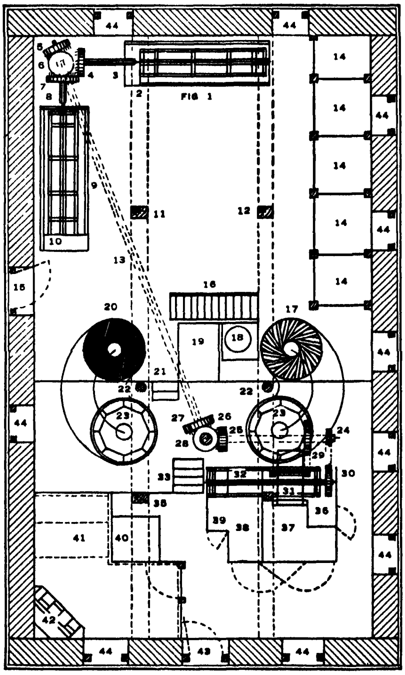
1 and 9. Bolting chests and reels.
3 to 8. Shafts and wheels to turn the reels.
13. Long shaft between uprights.
14. Five garners to hold toll, etc.
15. Door in upper side of millhouse.
16, 21, and 33. Stepladders.
17. The running burr millstone laid off to be dressed.
18. Hatchway.
19. Stairway.
20. The running country stone turned up to be dressed.
22. The places where the cranes stand.
24 to 31. Shafts and wheels for rolling screen.
32. The rolling screen.
36. A small room for tailings of screen.
37. A room for the fannings.
38. A room for the screenings.
39. A small room for the dust.
40. A penstock of water.
41. A room for the miller to keep his books in.
42. A fireplace.

Plate XVIII.



Ground floor

Plate XIX.



Second floor

FIG. 6. *Plant layout in 1790.* Thomas Ellicott's "draughts" for building a gristmill, 32 × 55 ft, three stories high. From engraved copperplates drawn on scale of $\frac{1}{8}$ in. = 1 ft. (*Reproduced from Oliver Evans'* The Young Mill-wright and Miller's Guide, *Philadelphia, 1795.*)

venture. The need for a layout project therefore stems from sales requirements and manufacturing costs. Overtaxed production capacities or high manufacturing costs are the usual initial barometers of the need to consider a rearrangement of the existing layout or the development of a new one.

2. REVOLUTIONARY CHANGES IN PLANT LAYOUT DESIGN

Advent of Industrial Engineering

Plant layout engineering which, as indicated in Figure 6, had been in existence as far back as 1790, was already 120 years old in 1910, when scientific industrial management made its first effective appearance. Although it had never been recognized as a separate engineering science, plant layout had remained as a dominant factor of production throughout the development of the factory system. Following the establishment of industrial engineering as a science in 1910, plant

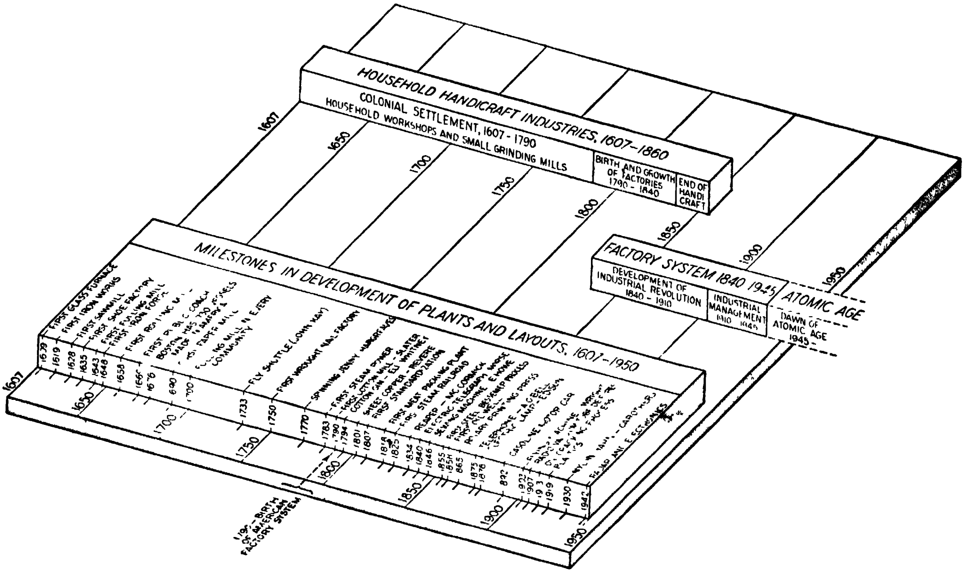

HOUSEHOLD HANDICRAFT INDUSTRIES, 1607-1860
COLONIAL SETTLEMENT, 1607-1790
HOUSEHOLD WORKSHOPS AND SMALL GRINDING MILLS
BIRTH AND GROWTH OF FACTORIES 1790-1840
END OF HANDICRAFT
FACTORY SYSTEM 1840 1945
DEVELOPMENT OF INDUSTRIAL REVOLUTION 1840-1910
INDUSTRIAL MANAGEMENT 1910 1945
ATOMIC AGE
DAWN OF ATOMIC AGE 1945
MILESTONES IN DEVELOPMENT OF PLANTS AND LAYOUTS, 1607-1950
1790-BIRTH OF AMERICAN FACTORY SYSTEM
1607
1650
1700
1750
1800
1850
1900
1950

FIG. 7. *Industrial stages and milestones in plant development in the United States, 1607–1950.* The year 1790, when the first cotton mill was established by Samuel Slater in Pawtucket, R. I., is generally recognized as marking the birth of the American factory system. Milestones in the development of manufacturing establishments, from 1607 to 1950, are arranged chronologically in the chart above. (*Courtesy of Gaudreau, Rimbach & Associates, Pittsburgh.*)

INDUSTRIAL STAGES IN THE UNITED STATES, 1607–1950

1. Handicraft industries—253 years old at close
2. Factory system—110 years old in 1950
3. Industrial management—40 years old in 1950
4. Atomic energy, dawn of new era—1950

Plant layout, 1790–1950—160 years old in 1950

BIBLIOGRAPHY ON HISTORICAL DEVELOPMENT

J. L. Bishop, *History of American Manufactures from 1608 to 1860*, 3 vols., 1866.
H. E. Faulkner, *American Economic History*, 783 pages, third edition, Harper and Brothers, 1935.
A. M. Saloski and M. L. Hoch, *American Economic Development*, 431 pages, Thomas Nelson and Sons, 1936.

layout engineering was engulfed as a branch of that new science along with such innovations as time and motion study, methods engineering, cost accounting, and production control. Milestones in plant development are shown in Figure 7.

Plant Layout Espoused by Time Study

With successive developments of time-study standards after 1910, managements began to recognize that rearrangements in plant layout were necessary to permit a full realization of the benefits of time study. While attention was being focused on extracting the last ten-thousandth of an hour of labor content in a machine operation, material-handling limitations were encountered which voided such infinitesimal values in machine operations unless required changes were duly made in plant layout.

Former Jungle of Line-Shaft Belts

Before the advent of electricity as a prime mover in industry, machinery was belted to line shafts driven first by a water wheel and later by a steam engine. The most conspicuous characteristic of the machine shop of as late as 1915 was the jungle of belts that completely occupied the overhead space to the ceiling. Running off from the main shaft, which usually extended the full length of the plant, was a motley arrangement of countershafts, each with its complement of pulleys and belts linked to the machines, not to mention the array of belt-shifters dangling down from the ceiling.

With the introduction of the electric motor, the belts remained in many plants and were simply linked to the motor after the pulley ratios were changed. This system was followed by the group drive, which succeeded in breaking the proverbial long main shaft into sections. It was not until the individual motor drive for each machine tool was introduced that the line shafts and belt jungle were eliminated.

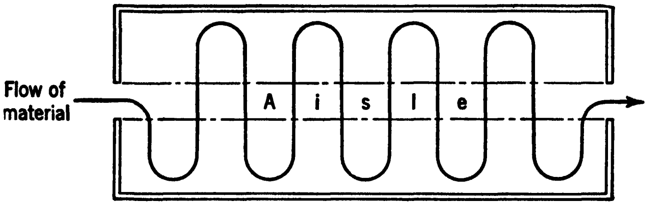
Inheritance of Line-Shaft Age in Existing Layouts

Much of present-day thinking as related to plant layout goes back to the days of line shafting and group-driven machines, the days before conveyors, suspended cranes, tiering machines, portable bins, and other material-handling devices developed only during the past 30 years. A striking example of this form of thinking is evident in the present location of many factory aisles. Many a plant today is bisected by an aisle running directly through the middle of the building, as illustrated in Figure 8. This usually results in two long narrow work areas from which the material in process zigzags across the aisle in moving from operation to operation. Such an aisle arrangement dates back to the days when line shafting necessitated locating the machine tools in two long parallel rows.

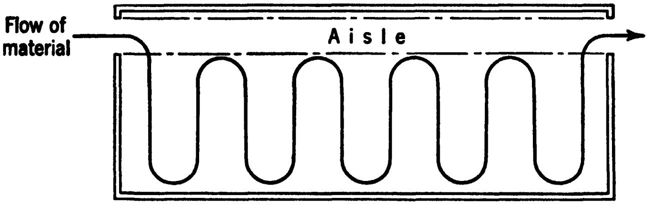
Grouping the machines performing similar operations has in many cases given way to laying them out in the sequence of operations through which the product is processed. In this way, instead of transporting the product continually, from one group of machines to another, for miles of traveling and backtracking, the machine itself is moved to accommodate the flow of the product.

Layout Invades the Field of Architecture

The influence of material handling in turning the attention of management to the neglected subject of the importance of plant layout design is significantly reflected in the evolution of plant architecture since World War I, when large-scale production as we know it today became established. It was not until then that serious consideration was given to the dominating factor of material handling in expediting production and lowering operating costs.



A. Bisecting aisle. Manufacturing area bisected by an aisle, giving two "stringbean" work areas resulting in inefficient layout and handling.



B. Side aisle. Same manufacturing area with aisle on one side. Full width of manufacturing area can be utilized without having material crisscross the aisle.

FIG. 8. *Location of factory aisles.*

The plant building, which heretofore had been considered only a shelter for housing manufacturing activities, suddenly developed into a series of plant types, such as the vertical-flow plant, the horizontal-flow plant, and the functional one-floor plant of today. Each successive plant type vied with the preceding one in facilitating material handling. With the advent of World War II the trend swung to the integration of plant layout designs into a compound plan to operate the entire plant as one gigantic production machine, with management at the controls. The layout thus became the blueprint of the whole plant as a unit.

3. PLANT LAYOUT AS A PRIME FACTOR OF PRODUCTION

Appraisal of Underlying Facts

The proper design of a plant layout, as previously indicated, is the joint product of the various divisions of management in an enterprise. It calls for a scientific appraisal of all relevant facts that influence the layout and that are reciprocally influenced by it. These facts stem from physical limitations, production activity, sales requirements, investment outlays, operating costs, resulting profit, and optional plans.

In the selection of a crane, for example, it is necessary to gather and weigh facts not evident at the drafting board. Some of these facts are:

1. The maximum weight to be lifted.
2. The volume of work to be handled.
3. The number of cranes required for this volume.
4. The combined cost of the crane, craneways, and column supports.
5. The operating cost of labor, power, repairs, and depreciation of the crane installation.
6. The effect on the gross profit of the particular volume of production to be handled by the crane.
7. The expected duration of the business requiring the use of the crane.
8. Optional material-handling devices that could meet the handling requirements as economically, or perhaps more so.

These eight points have been listed in the order in which they can be developed logically. Only too frequently the decision is made on the basis of point 1, to the exclusion of the remaining seven considerations. Any one of these points may carry as much, if not more, weight in a proper appraisal of the project as does the more obvious first point.

Hidden Losses in Poor Layouts

Because of the far-reaching and hidden effects of plant layout, its real importance is not obvious to the average foreman or manager. Many an executive would be surprised to learn the amount of saving that could be realized from an efficient layout. This saving often justifies the construction of an entirely new plant. Experience often shows that no factor of production causes greater waste of operating cost, a waste that remains hidden, than does the improper physical layout of a plant. Present methods of accounting do not show the money lost in unnecessary material handling, wasted motions, extra steps, etc., occasioned by poor layout. The manager, who is impressed only by the things he can see or feel, often overlooks improper layout and fails to recognize it as a major cause of high costs.

The conversion of raw material into a finished product is done in three basic operations: (1) processing, (2) assembling, and (3) material handling. In the evolution of the factory system, attention has been focused upon the first two operations simply because they directly affect the product. The greater potentials in cost reduction hidden in material handling have remained largely untapped. Because of the search for continually lower costs and because of the recurrent need for expanding production facilities, plant layout has, during the past 30 years, become an increasingly important factor of plant operation.

Unsystematized Plant Expansion

Recognition of the importance of plant layout is reflected in some industries in assigning competent engineers to layout problems. For it is through plant layout that a number of troubles may be avoided, such as idleness, bottlenecks, excessive maintenance, operation hazards, and a number of labor problems.

Where a plant is the outgrowth of unsystematized expansion, there is little logic in the arrangement of much of the machinery. What manager has not dreamed of the day when he could make a clean sweep of his plant and rearrange the machinery and equipment to suit present and contemplated production requirements?

More Material Handling than Processing

The fundamental part occupied by material handling in the productive process, and the major portion of the labor cost incurred in material handling while the processing of the product is taking place, are both evidenced in the simple operation of drilling holes. A recent survey made for the purpose of determining the efficiency and cost of drilling holes showed that only 20 percent of the actual time allowed an operator for drilling holes was spent in the actual removal of metal in the part being drilled. The other 80 percent of the time was spent in preparing the material under the drill before the actual drilling could start.

Now assuming that, by using better steels, better drill design, and improved machine efficiency, the operation of drilling the hole could be improved 10 percent. This gain would amount to 10 percent of the time consumed in removing the metal, or an over-all gain of only 2 percent. Had the 10 percent improvement been made on the 80 percent of the time lost in handling the material before drilling it, the resulting over-all gain would have amounted to 8 percent, or 4 times what was obtained from the process itself.

Greater Saving from Layouts than from Machines

Although these percentages vary with different operations, the greater portion of time taken up in most machine operations is in material handling. Yet industry continues to spend thousands of dollars and thousands of man-hours in improving machines and tooling setups, and often overlooks the greatest source of loss of time and money in operating these machines, namely, the transportation of material from machine to machine and the handling of the material at the machine itself.

The principal reasons for this neglect are the fact that the true cost of material handling is not made known by accounting records, and the fact that the latent advantages of good plant layout remain hidden except to competent engineers familiar with the far-reaching effects of plant layout. A machine can be seen, heard, and felt, but plant layout is an elusive something which has to be visualized mentally, studied carefully, and designed from specialized experience.

4. THE ADVANTAGES OF A GOOD PLANT LAYOUT

The objectives and ideals of plant layout are perhaps best described in the advantages derived from a good layout. No attempt is made at this point to evaluate the advantages individually. Depending upon the size of a plant, its existing layout and equipment, its age and physical condition, its type of manufacturing, the nature of its product, etc., the relative value of a particular advantage of good plant layout will necessarily vary from plant to plant, for no two plants are likely to have an identical set of circumstances.

Layout Advantages Not Restricted to Plant Size

Whether a plant employs 50 workers or 50,000 makes no difference in so far as the applicability of plant layout advantages is concerned. A large plant, after all, is but a series of small plants under a common roof, or such it should be to achieve the best results. The present movement to decentralize large plants into smaller operating units located in separate localities is a recognition of the extra advantages possessed by the small plant over the mammoth enterprise.

Fundamental Concepts of Plant Layout

In appraising the advantages of good layout in the light of conditions prevailing in a particular plant, it is well to bear in mind the following fundamental concepts of plant layout:

1. The major part of production work is **not** processing, as is usually supposed, but material handling.
2. The speed of production in a plant is determined primarily by the adequacy of its material-handling facilities.
3. A good plant layout is designed to provide the proper facilities for material handling as well as processing.
4. The factory building is altered or constructed around the prescribed plant layout design.
5. The production efficiency of a plant is determined by the limitations of its layout.

The factory building itself is still only a housing for machines, material, and workers. In this respect, the modern plant differs from that constructed before World War I in that the new plant houses a scientifically planned layout, whereas the old-fashioned plant provided but an architectural shelter inclosing a chance collection of machinery and equipment. The progress made in recent years in designing industrial buildings is illustrated in Figures 9 and 10.

Manufacturing Activities Affected by Plant Layout

In a modern plant, the manufacturing activities and end results that are affected directly by plant layout may be summarized as follows:

1. The distance traveled by the parts or worked material in the course of their manufacture.
2. The time consumed in this travel.
3. The number of processing operations and their related sequence.
4. The manufacturing cycle for the product.
5. The cost of receiving and storing the materials.
6. The cost of transporting the materials, work in process, and finished products through the plant.

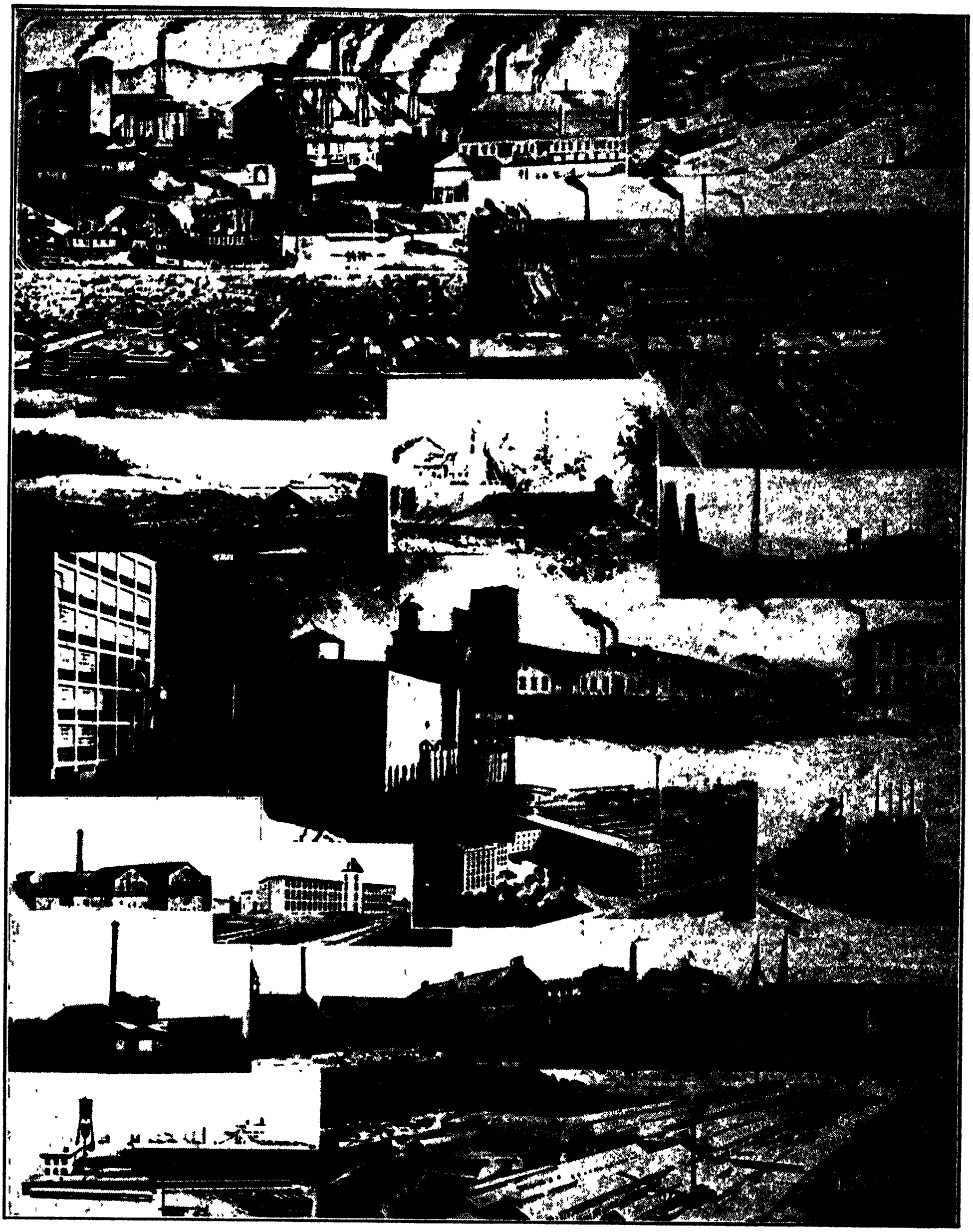


FIG. 9. *Antiquated plant designs.* Industrial architecture before World War I.

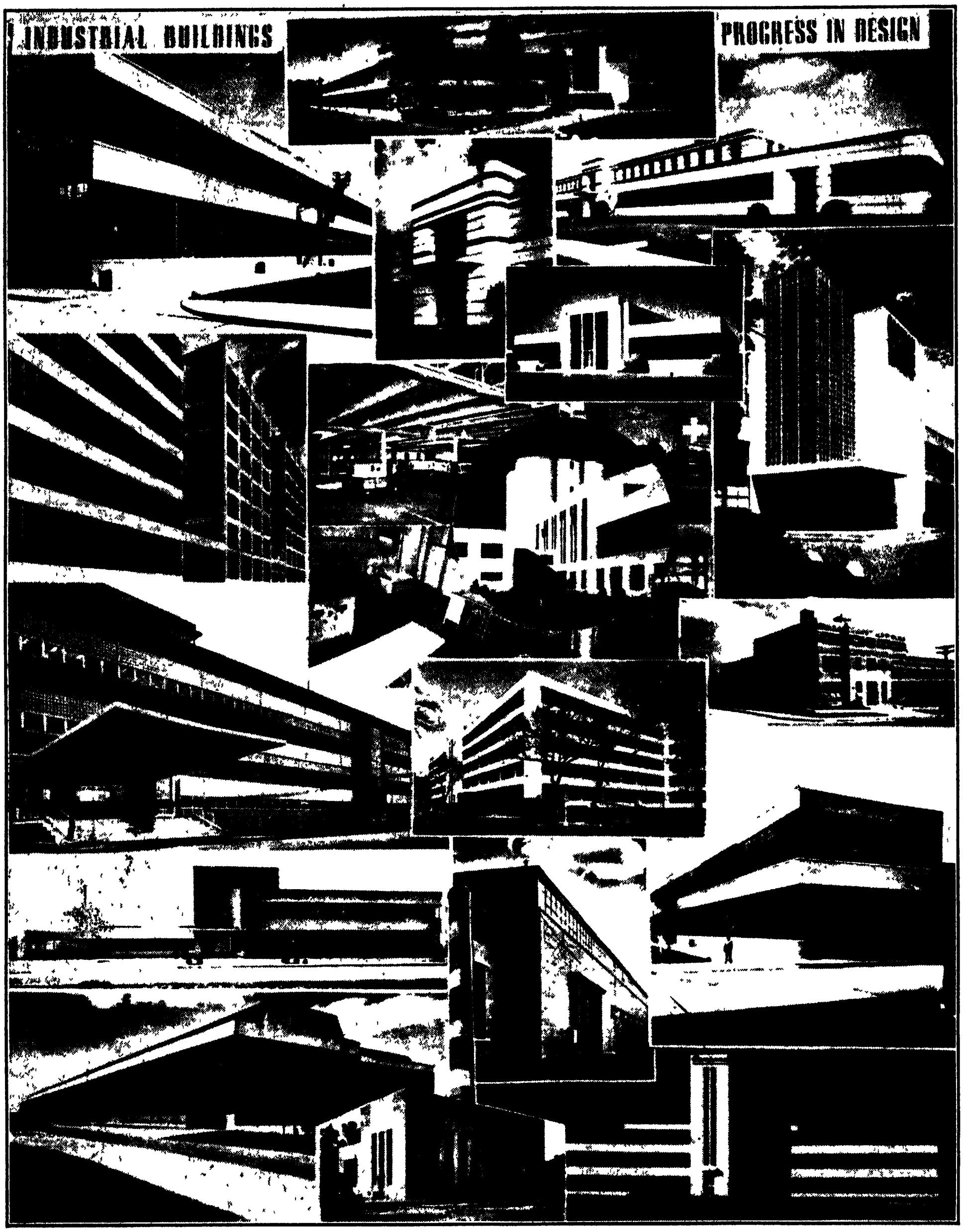


FIG. 10. *Modern plant designs.* Although much progress has been made in plant design, even today buildings are planned with 1900-model layouts. Consequently, some of these modern exteriors pictured above may house inefficient layouts.

7. The cost of time lost by the process worker in preparing, handling, and removing the material at the machine.
8. The selection of manufacturing methods, machinery, manufacturing equipment, and material-handling equipment to permit the worker to become a producer instead of a material handler.
9. The installation of safety measures to guard against industrial hazards.
10. The flexibility of plant capacity to meet changing needs and future expansion.

Increasing Productivity through Better Layouts

The increased productivity per man-hour is what has permitted higher wages and lower prices in the industrial development of this country. However, more production does not necessarily connote harder work. To the contrary, greater production may be attained, not only without harder work but usually with less effort, simply by a better application of plant layout engineering principles. As already indicated in preceding pages, the only real ceiling on wage rates is the worker's ability to earn, but the plant must be laid out and organized so as to permit the wages to be earned, and without greater effort. How a revised layout of an assembly line for a gear-motor unit increased the output by 47 percent is illustrated in Figure 11.

Advantages Derived from Efficient Plant Layouts

The advantages derived from a plant layout which has been properly designed, and the improvements generally evident in such a plant, are briefly described below from the standpoint of the worker, the labor cost, other manufacturing costs, the manufacturing cycle, production control, supervision, and capital investment.

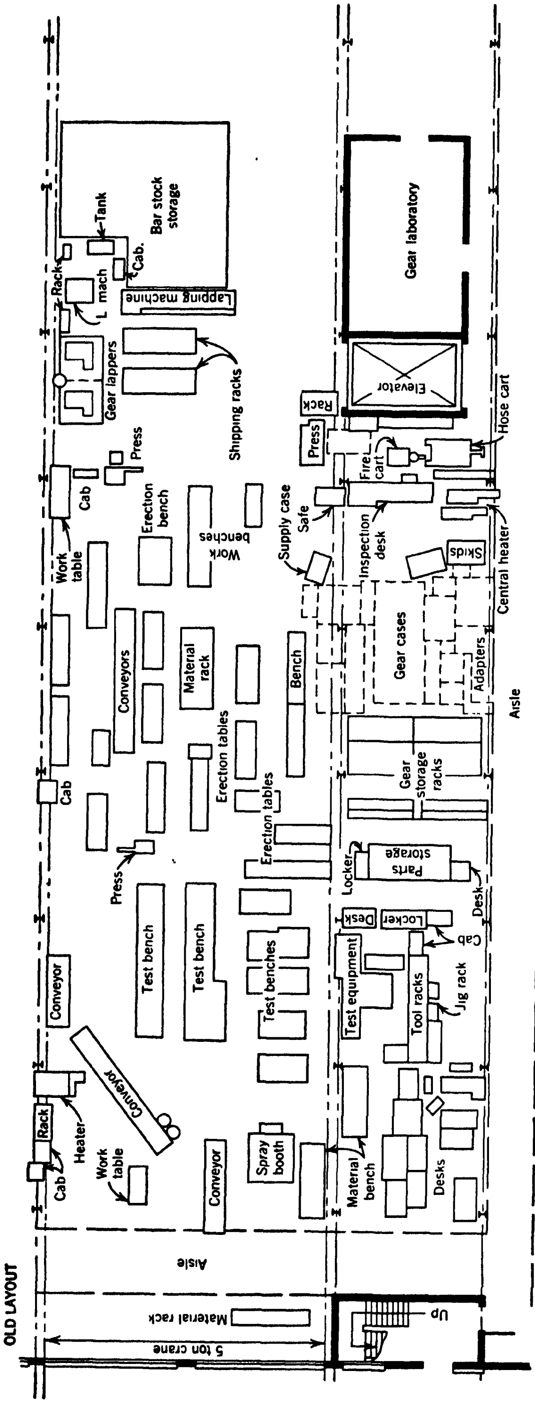
THE ADVANTAGES OF A GOOD PLANT LAYOUT

A. To the Worker

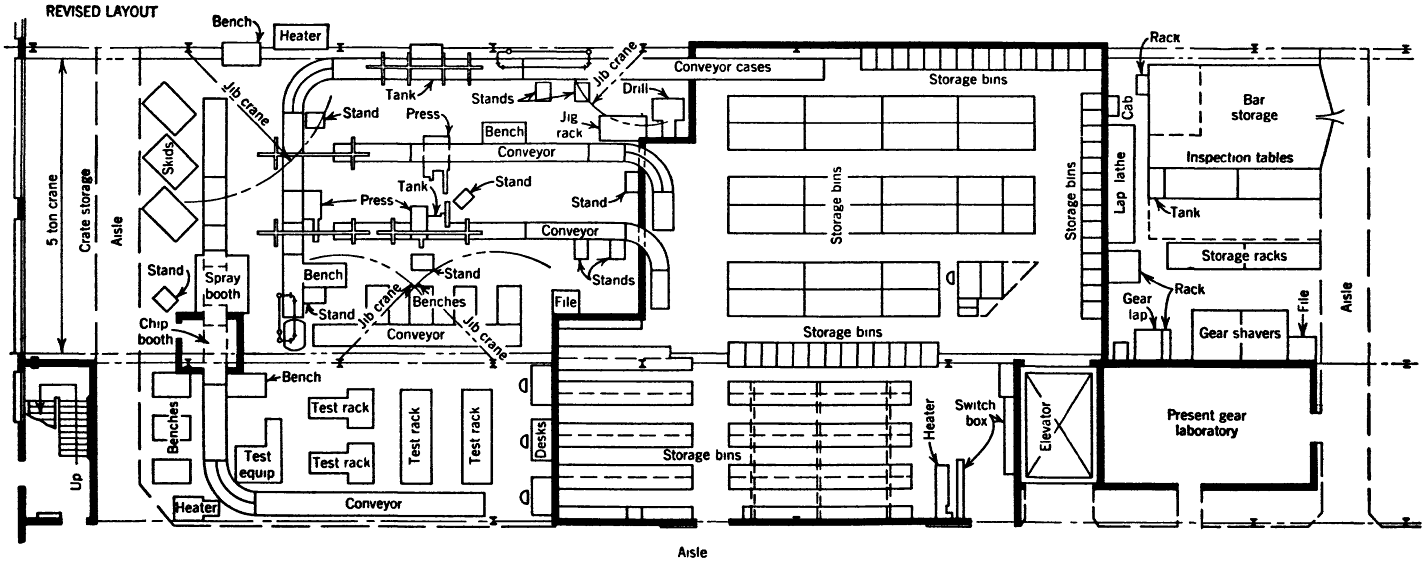
1. Reduces the effort of the worker.
2. Reduces the number of handlings.
3. Extends the process of specialization.
4. Permits working at maximum efficiency.
5. Better working conditions by eliminating congestion.
6. Reduces the number of accidents.
7. Provides better employee service facilities.
8. Provides basis for higher earnings.

B. In Labor Cost

1. Increases the output per man-hour.
2. Less setup time involved.
3. Reduces the number of operators.
4. Reduces the number of handlers.
5. Reduces the length of hauls.
6. Minimum lost motions between operations.



A. *Old layout.* Each operator worked more or less individually, and very little mechanical handling equipment was used.



B. Revised layout. Conveyors are used to transport material between successive operations. Work stations are arranged to permit operators to perform only a few specialized functions, thereby improving operator efficiency and product quality. As a result, production is increased 47 percent.

FIG. 11. *Output increased 47 percent* by revised layout of an assembly line for a gear-motor unit. (*Courtesy of Gaudreau, Rimbach & Associates, Pittsburgh.*)

7. Converts the operator into a producer, instead of a handler, by eliminating the following motions at the machine:
    - *a.* Walking time to procure the work.
    - *b.* Taking the work to the machine.
    - *c.* Turning around for the work.
    - *d.* Returning the work when the operation is completed.

C. In Other Manufacturing Costs

1. Reduces the cost of expense supplies.
2. Decreases maintenance costs.
3. Decreases tool replacement costs.
4. Effects a saving in power loads.
5. Decreases spoilage and scrap.
6. Eliminates some of the waste in raw material consumption.
7. Improves the quality of the product by decreasing handling.
8. Provides better cost control.

D. In the Manufacturing Cycle

1. Shortens the moves between work centers.
2. Reduces the manufacturing cycle in each department
3. Reduces the length of travel by the product.
4. Reduces the over-all time of manufacturing the product.

E. In Production Control

1. Facilitates receipts, shipments, and delivery.
2. Provides adequate and convenient storage facilities.
3. Permits the maximum possible output.
4. Paces production.
5. Determines production flows.
6. Makes production time predictable.
7. Makes scheduling and dispatching automatic.
8. Sets up production centers.
9. Permits straight-line layout by products for mass production.
10. Permits layout by process for job-lot manufacturing.
11. Moves work in process by most direct lines.
12. Reduces the number of lost or mismatched parts.
13. Reduces the paper work for production control.
14. Reduces the number of stock chasers.
15. Reduces production control expense.

F. In Supervision

1. Tends to ease the burden of supervision.
2. Determines the supervisory control.
3. Reduces the cost of supervision.
4. Reduces the cost of piece counts.
5. Decreases the amount of inspection.

G. In Capital Investment

1. Holds permanent investment at a minimum.
2. Adapts plant to present manufacturing methods.

3. Provides for changed methods and future expansion.
4. Keeps plant from becoming obsolete before it is worn out.
5. Reduces investment in machinery and equipment by:
    - *a.* Increasing the production per machine.
    - *b.* Utilizing idle machine time.
    - *c.* Reducing the number of operations per machine.
6. Maintains a proper balance of departments.
7. Eliminates wasted aisle space.
8. Reduces the floor space and shop areas required for manufacturing.
9. Reduces the amount of material-handling equipment required.
10. Reduces or eliminates elevator service.
11. Reduces the inventory of work in process and of finished products.

At this point, space does not permit going into detailed descriptions or illustrations of these 58 plant layout advantages commonly encountered, in part at least, in plants where the layout has been properly planned and installed. Applications of these points form the subject matter of Parts 2, 3, and 4 of this book. A specimen illustration of what a plant modernization program has done for a ceramics plant is given in passing, however, in Figure 12.

5. CONDITIONS SIGNIFYING AN IMPROPER PLANT LAYOUT

Inefficient Operating Conditions

Aside from the economic needs indicating that a change in plant layout should be considered, a number of inefficient operating conditions, not usually reflected in accounting figures, provide unmistakable evidence of a deficient layout. Most of these unrecorded deficiencies are readily recognizable to the trained observer, and the existence of any or several of them quickly points to the need for at least a restudy of plant layout, if not for an immediate new layout design. The more common of these indications may be grouped under the following six headings:

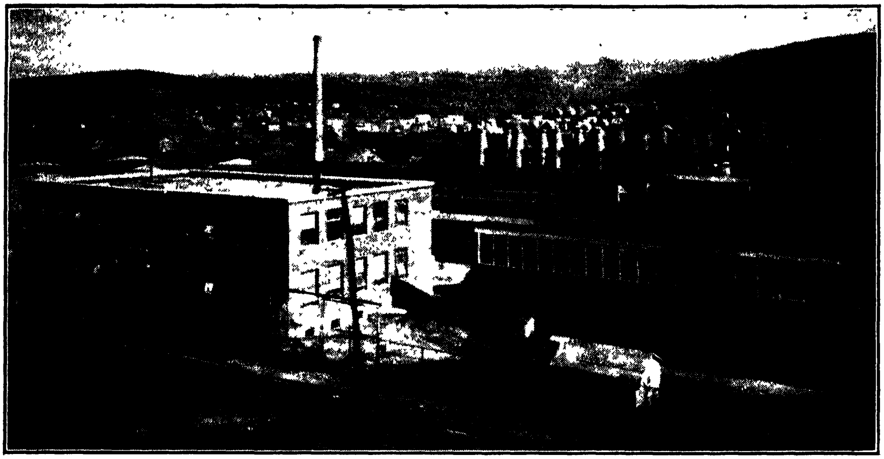
1. **Receiving department.**
    - *a.* Congestion of materials.
    - *b.* Complaints of delays at trucking lines.
    - *c.* Recurrent demurrage.
    - *d.* Damage to materials by exposure to the elements.
    - *e.* Necessity for material handlers to work outside in inclement weather.
    - *f.* Difficult manual handling and rehandling operations.

2. **Storerooms.**
    - *a.* Congestion of stock storage.
    - *b.* Damage to materials in storage.
    - *c.* Frequent loss of material.
    - *d.* Poor control of inventories.
    - *e.* High ratios of storeroom clerks and material handlers to productive operators.
    - *f.* Frequent rehandling and restorage of materials before processing.

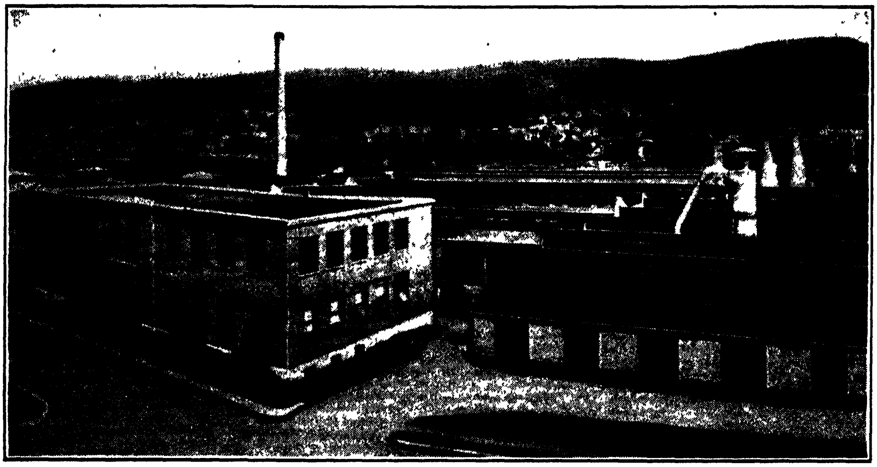
3. Process departments.

a. Necessity for skilled operators to handle materials.

b. Presence of large quantities of materials on the floor, not under production control.



A. Before modernization. A ceramics plant with old-style kilns that required hand loading and a slow-firing cycle.



B. After modernization. The same plant after the old-style kilns have practically all been removed and replaced by car-type, gas-fired, and oil-fired, continuous kilns. Modern methods, equipment, and the "new look" have already invaded this age-old industry.

Fig. 12. *Modernization of a ceramics plant.* Replacement of old-style kilns by mechanized continuous units transforms an old ceramics plant into a modern establishment.

c. Poor quality of work in process.

d. Complaints from foremen and production supervisors regarding the lack of floor space while overhead space remains unused.

e. Excess length of the manufacturing cycle over actual processing time.

f. Presence of congestion and hazards in narrow or crooked traffic aisles.

g. Over 15 percent of the total floor space in the plant taken up by traffic aisles.
h. Difficulty in the material-handling service to the productive equipment.
i. Excessive maintenance costs.
j. Necessity for frequent rearrangements of equipment.
k. Periodic requests for additions to equipment or to the working area.

4. Productive operators.

The existence of any of the following excesses in material-handling work performed by productive operators:

Material-Handling Condition	Male Operator	Female Operator
a. Lifting material frequently from floor level to	A point overhead	Chest height
b. Lifting material above knee level when weight exceeds	75 lb.	35 lb.
c. Lifting or moving material with the assistance of	1 helper	1 helper
d. Handling materials constantly for periods longer than	30 min.	30 min.
e. Handling similar materials daily for	Several weeks	Several weeks
f. Moving large quantities or total weight over greater distance than	50 ft.	50 ft.

5. Employee morale.

a. Complaints from operators regarding:

(1) Heating
(2) Lighting
(3) Ventilation
(4) Rest rooms
(5) Congestion
(6) Hazards

b. High accident rate.
c. High labor turnover.

6. Shipping department.

a. Delays in shipping even though materials are ready for shipment.
b. Unsightliness of plant yards.

Other common indications, such as disorganized production schedules, excessive payrolls, and low worker interest in operations, are traceable directly to an improper plant layout. Experience has demonstrated time and again that no factor in manufacturing activities causes greater losses in operating efficiency, without being readily detected, than does a poor physical layout. Yet it is one factor that frequently receives only scant attention largely because of the lack of a proper evaluation of plant layout effectiveness.

6. PRIME OBJECTIVES IN CONTEMPLATING A RE-LAYOUT

Elimination vs. Simplification of Operations

The engineering approach to a problem is through the analysis of existing methods and practices for possibilities of making improvements. Simplifying an operation, however, does not justify its retention. The possibility of eliminating the operation entirely is often overlooked because its very existence is taken for granted, especially by employees who have been in contact with it over a number of years. Much of the layout work done today is based on simplification rather than on elimination where possible.

The tendency to question the very existence of a method or operation is more natural to an outside engineer than to one in the company's employ. This largely accounts for the feeling in many quarters that the only engineer who can do a plant layout job correctly is the professional consultant from outside the company. Coming into the plant for the first time, the consultant naturally questions the reason why an operation is performed in the first place, and leaves the possibility of simplifying this operation for later consideration after he is convinced the operation cannot be eliminated entirely.

Plant layout work that is confined to the simplification of operations, often on a single machine or a limited part of a process at a time, generally secures only a small portion of the potential improvement or savings because it does not consider the problem to the extent of totally eliminating the operation. This type of layout work is the most common and is concerned mostly with cost reduction, which is but one of the purposes of a plant layout.

The prime objectives that give rise to the necessity for a layout are enumerated in the following summary.

PRIME OBJECTIVES OF A NEW LAYOUT

1. **Increased capacity.** To expand the output of existing products or to provide for the addition of new products.
2. **Consolidated activity.** To group together the manufacturing of like products, the demand for which has increased in some and decreased in others, so as to balance the machine capacity available.
3. **Shrinkage in output.** To reduce the floor space occupied by products of older design, the demand for which has been shifted to new designs but which must be kept in production on a limited basis.
4. **Change in location.** To transfer the production of certain products to other departments or plants to secure some, if not most, of the advantages of good layout.
5. **Cost reduction.** To make it possible to realize some of the potential savings accruing from improved machinery, mechanized material handling, and other operation facilities, all within a given layout area.

In short, the over-all governing objective of a new layout is an attempt to **fit the building to the process** by rearranging the equipment and making alterations to the building itself whenever justified, to expedite the flow of work at minimum cost. Although many of the older plants have been constructed without a preplanned layout, a scientific rearrangement of existing facilities usually results in achieving the greater portion of the advantages of a good layout, but the arrangement is not so effective as when planned before the building is erected.

CHAPTER III

Range of New Layout and Re-Layout Projects

1. LAYOUT STAGES FROM JOB LOTS TO MASS PRODUCTION

Continuous Changes Being Made in Plant Layouts

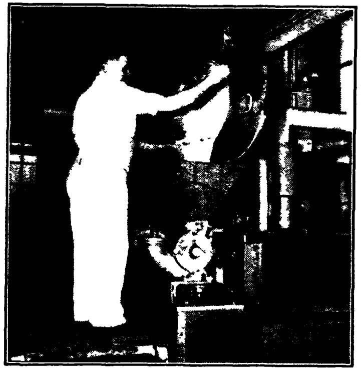
Changes in layout range all the way from moving a workbench a few feet at a work station to the rearrangement of an entire building or series of buildings on the same premises. As many as 75 layout changes are made each week in some large plants, and these changes must usually be made without interrupting operations. Often the existing buildings are found inadequate, and the cost of building new plants becomes more economical than that of modernizing old plants.

Three Stages of Growth in Manufacturing

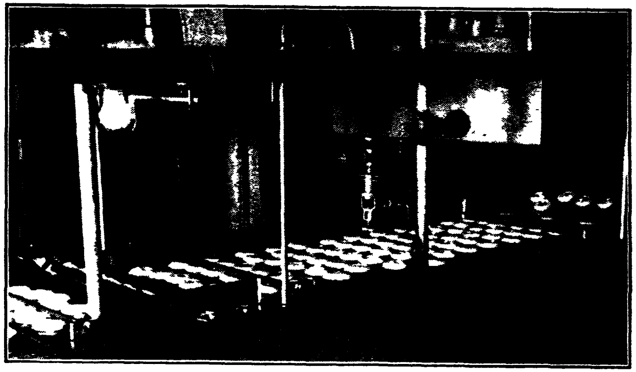
Whether the layout change is confined to slight revisions of arrangement or involves a complete remodeling of existing facilities, it is necessary to determine at the outset the particular position which the manufacturing activities involved occupy in the over-all cycle of manufacturing development. As the market demand grows for given products, their production tends to go through three successive stages of manufacturing development. Very few ever reach the third stage, and still less ever begin at the third stage. These three stages range from small-quantity job lots to mass production in the following order, in an assembly industry:

1. **Small job lots with little or no assembly.** Small quantities within a short manufacturing period, on a job-lot basis, produced by tooling up to use existing machinery and plant facilities. This stage requires either no change in layout or only minor changes for added facilities within the general machinery department, to accommodate certain operations.
2. **Job lots assembled outside the machining department.** Job-lot machining justifying special assembly outside the general machining department proper, marks the starting point in advanced plant layout design as manufacturing operations on some products begin to expand. The problems of economical material handling between departments and of proper balancing of machines and operations begin to emerge at this point. Along with the advent of these problems arises the need of proper plant layout design.

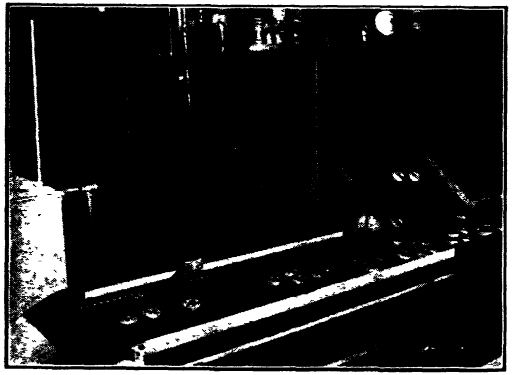
A. Automatic dough mixer. The proportionate amount of each ingredient in the dough mixture is measured by a scale. Water is automatically metered and the mixing is accurately timed.

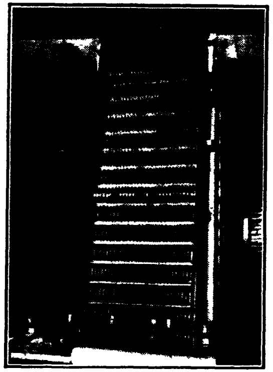


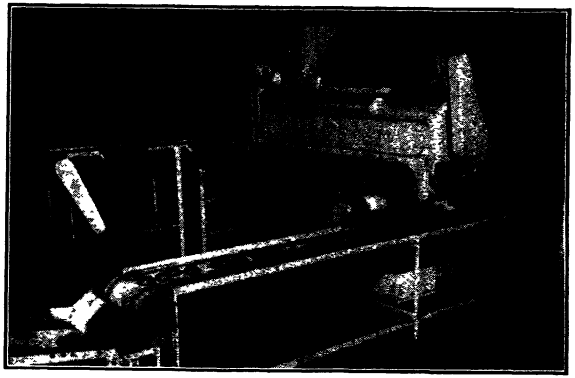
B. Overhead crane. An overhead crane moves the kettle of mixed dough from the mixer to the doughnut cooker. The kettle of dough is then emptied into the machine that shapes the doughnut.



C. Doughnuts on parade. Six doughnuts, cut one row at a time and arrayed in rows of six, drop into the melted grease with the precision of cadets on parade. Every 3 seconds another squad of 6 joins the drill. Halfway along the 8-foot trip through the cooking machine, the doughnuts are flipped.



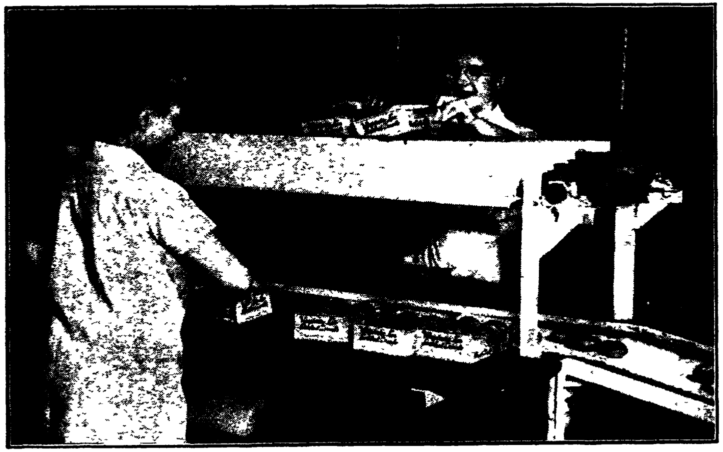




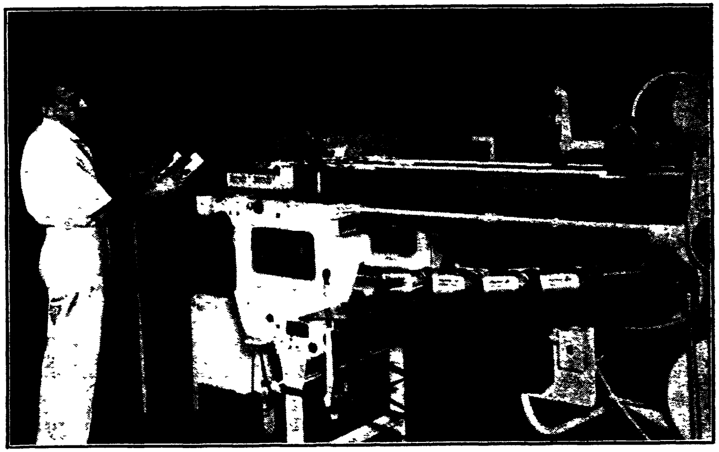
D. Cooking in transit. In 3 minutes, the doughnuts travel the length of the 8-foot cooker. The hot grease through which they pass is heated by a liquid chemical that circulates through the cookers. The chemical liquid undergoes continuous heating in the basement of the bakery, and circulates between the boiler and the cookers as in a household hot-water heating system

E. Cooling in motion. From the cooking machine, the doughnuts are automatically conveyed to a cooler and carried up 12 feet to the top of this machine. The cooler is a glass-inclosed chamber, 30 feet long. In the cooling process, conveyors continually move the doughnuts back and forth in the chamber for 45 minutes.

F. Through a sugar shower. The sugar in the hopper on top of the sugaring machine sifts over the doughnuts rotating in a perforated cylinder inside. In this operation, the doughnuts are coated uniformly and then automatically discharged onto a belt conveyor which takes them to the packaging operation.



G. Packaging operation. As the doughnuts near the end of their baking trip, they are removed from the belt conveyor (bench height) and packed in boxes. The filled boxes are immediately placed on a return conveyor above the work bench. The boxes are now on their way to a wrapping machine.



H. Automatic wrapping machine. Each box is automatically wrapped in cellophane and the cellophane is sealed by an electric heating unit. At this point, the package is inspected through its transparent sealed top while being removed from the machine and placed in cartons for shipment to the stores.

Fig. 13. *Mass production on straight-line, or product, basis.* The material-handling work formerly performed by productive operators in the baking industry has been almost entirely eliminated in several processes, as in the baking of doughnuts. Note the absence of operators as the

3. **Mass production of standardized products.** Repetitive operations on large quantities of a limited variety of standardized products justifying a complete and thoroughly engineered plant layout to take advantage of the economies inherent in mass production. Large-volume manufacturing of this type may be laid out on one of two bases, or on a combination of both:

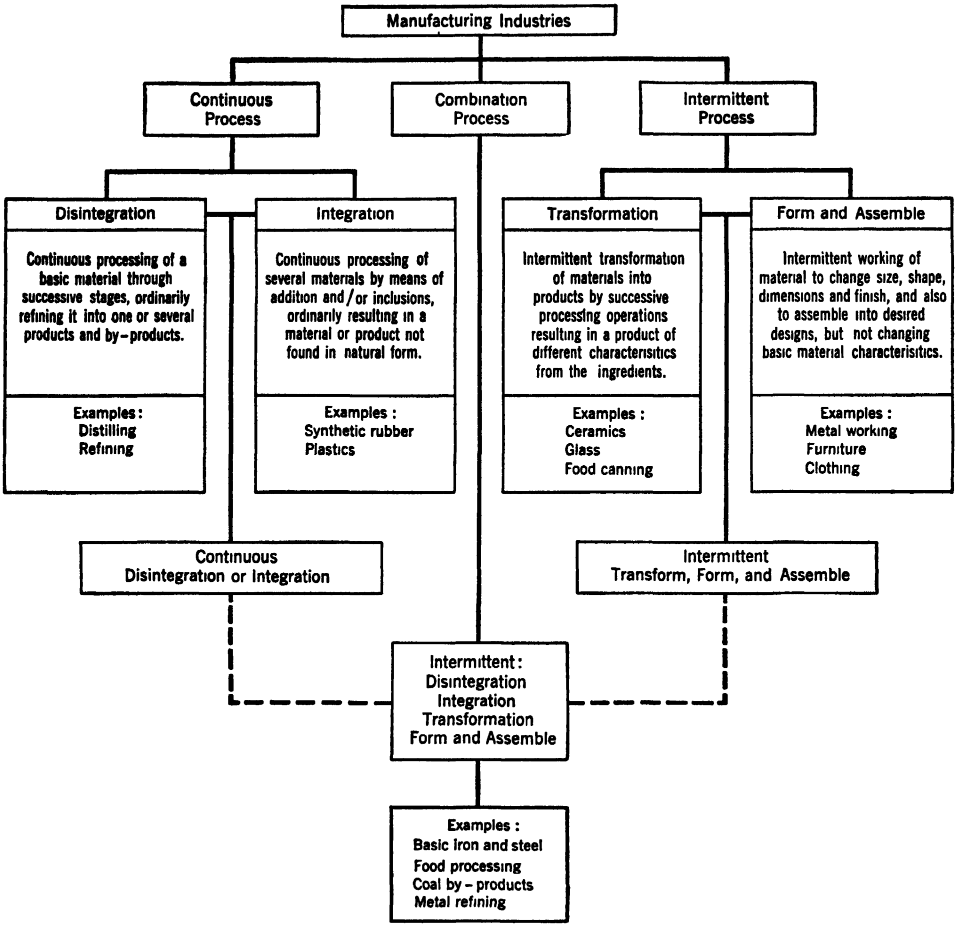

Manufacturing Industries
Continuous Process
Combination Process
Intermittent Process
Disintegration
Continuous processing of a basic material through successive stages, ordinarily refining it into one or several products and by-products.
Examples: Distilling Refining
Integration
Continuous processing of several materials by means of addition and/or inclusions, ordinarily resulting in a material or product not found in natural form.
Examples: Synthetic rubber Plastics
Transformation
Intermittent transformation of materials into products by successive processing operations resulting in a product of different characteristics from the ingredients.
Examples: Ceramics Glass Food canning
Form and Assemble
Intermittent working of material to change size, shape, dimensions and finish, and also to assemble into desired designs, but not changing basic material characterisitics.
Examples: Metal working Furniture Clothing
Continuous Disintegration or Integration
Intermittent Transform, Form, and Assemble
Intermittent: Disintegration Integration Transformation Form and Assemble
Examples: Basic iron and steel Food processing Coal by-products Metal refining

FIG. 4. *Types of plant layouts.* Owing to plant site, time of construction, caliber of management, nature of process, and many other factors, no two plants have identical layouts, even though their operations may be the same.

a. **Straight-line, or product, basis,** wherein the machinery is laid out, machine after machine, regardless of machine type, with all operations in their proper sequence, to follow the flow of the product in its progress through the variety of machining, processing, and assembling operations required. (See illustration of mass production on straight-line basis in Figure 13.) This is the most popular type of layout for certain parts of mass-production manufacturing.

b. **Functional, or process, basis,** wherein similar machine tools, such as punch presses, are grouped together in one location, such as a section, a department, or a building. This sets up the "punch shop," "screw-machine department," "drill-press group," etc., in separate locations. Although used in mass production, particularly in "feeder" divisions, this type of layout is generally better adapted for job-lot manufacturing or the large-quantity production of non-standardized products.

Much of the plant layout work done even today starts with an attempt to simplify operations, and is confined to the replacing of a few key operations with operations performed on more modern machinery. Then, by a minor rearrangement of existing equipment to make room for the new machinery or equipment, the resulting arrangement is presumed to be a new layout. In reality, this may be nothing more than a reshuffling of existing bad methods without eliminating or improving them and without making possible the attainment of more than a fraction of the returns on the investment for the new machinery and equipment.

No Two Plant Layouts Are Alike

Before any change is made in layout, it is necessary to analyze and synchronize the basic factors described in Chapter IV in order to secure the advantages of good layout outlined in Chapter II. These basic factors must be considered for the plant as a whole while at the same time being applied to a particular subdivision of the plant.

The range and relative size of plant layout projects that exist within a plant, or group of plants, are described in the remainder of this chapter. No two plants have identical layouts, even though their operations may be the same. (For a classification of types of plant layouts, see Figure 14.) This is due to many factors which vary from one plant site to another; to the conditions prevailing at the time the plant was originally constructed; and to the varying caliber of management in charge at different times in different plants.

2. THE WORK STATION AS THE BASIC SPACE UNIT

Smallest Indivisible Space Unit

The floor area occupied by the worker and the machine or group of machines which he operates is designated as the work place, or work station. It constitutes the smallest indivisible space unit on a layout and includes the following amount of floor space:

1. The rectangular space occupied by the length and width of the machine or group of machines operated by one worker, or a group of operators working as one unit, in a given area. This space is expanded to allow for travel of moving parts and for projecting machine parts, such as shafts, levers, pulleys, and doors.
2. Floor space for the machine's own motor or power source when placed on the floor or within the working area.

3. Working space for the operator.
4. Clearance for feeding the work on and off the machine.
5. Space for the skids, tote pans, racks, conveyor stations, etc., which either contain the work to be processed or receive the work after it has been processed on the machine.
6. Space for whatever tool racks, workbenches, and auxiliary equipment each particular machine may need for its operation.
7. Portion of the aisle space or conveyor space immediately adjacent to the operator, the machine, or the group of machines he operates.

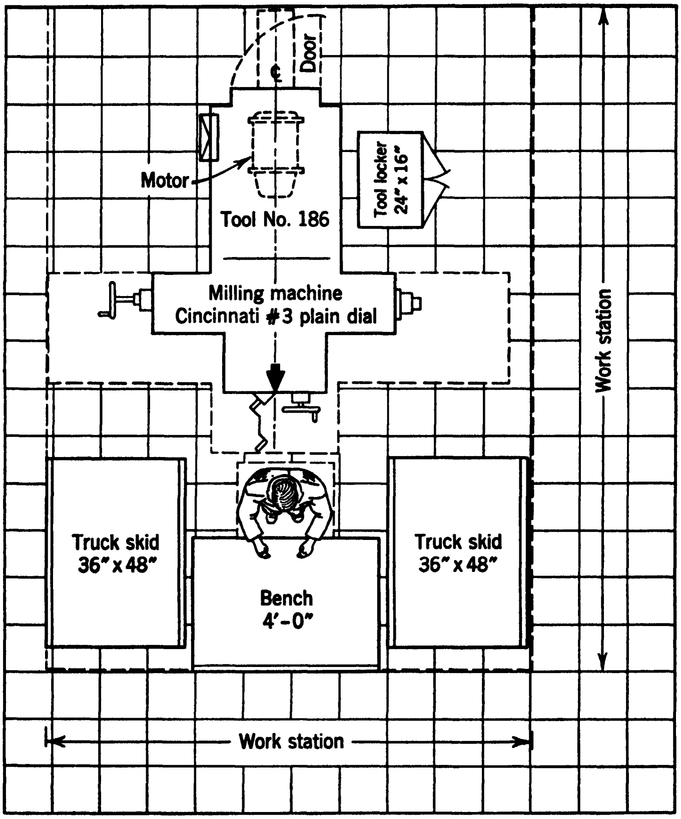


FIG. 15. *Work-station layout* for a No. 3 milling machine. Note that the complete work station requires much more space and more equipment than the machine itself would indicate. With the use of accurately designed two-dimensional templates the clearance area can be utilized for effective layout. The space in which the operator is standing also serves as clearance for the bench drawer. The tool locker is located adjacent to the machine in a space often overlooked when working with block templates. (*Courtesy of Gaudreau, Rimbach & Associates, Pittsburgh.*)

Work Station for a Milling Machine

The floor area required for a work station for a milling machine is laid out in Figure 15. The relationship and positioning of each constituent part of the work station must be studied from a thorough motion analysis of the manufacturing methods used and of the handling of materials while being received, processed, and then removed after completing the machine operation or operations. The correlation of individual work stations sets up the network of production units which are ultimately integrated to form the plant layout design. The area and internal arrangement of the individual work station may vary with each installation, depending upon its relative position to adjacent stations and to the amount of floor space available for the entire project, of which the work station is but one unit.

The Range of Greatest Motion Economy

For a given machine operation or assembly performance, the plant layout engineer must always bear in mind that the range of greatest economy lies within the area covered by the normal sweep of the worker's hands. Other things being equal, the worker in a fixed position performs his work in the most effective manner when the work is within the confines of this area. The instant the worker finds it necessary to reach outside the normal work area described by the sweep of his hands, his efficiency begins to suffer. If materials are brought to a worker at an uninterrupted rate, to a fixed position, and are removed from him at the same rate, the worker's effort is confined to productive purposes rather than being taken up by material handling. (See Figure 81.)

3. THE WORK CENTER INCLOSING AN OPERATING GROUP

The Machine Crew

As previously indicated, the work station is the floor area occupied by the worker and his machine or group of machines, plus the auxiliary equipment for the worker. This ensemble comprises an individual unit of production, or "work center." Sometimes the machine itself, instead of the worker, becomes the focal point of the production unit, or work center. In this case, the machine requires a crew of several operators in the category of loaders, actual operators, and unloaders. Such a machine crew is illustrated in Figure 16 for the operation of a flatwork ironer in a commercial laundry.

Machine crews as integral work centers exist in several industries. Examples are found in the operation of Foudrinier machines in the paper industry, prepared-roofing machines, continuous-strip mills in the steel industry, can-filling machines in the food, oil, and other packaging industries, incandescent-lamp making, electric-motor assembly, etc. In shipbuilding the only product is the entire ship itself, and each subdivision of the labor force becomes a production or work center for a section of the one finished product, namely, the ship.

Continuous-Process Industries

In a continuous-process industry, such as paint, chemicals, fertilizer, clay, paper, sugar, pottery, cornstarch, textiles, etc., the work center assumes a variety of types of internal composition, as may be gleaned from Figure 14. In such industries, the work center ranges from a "tank farm" or a network of pipelines or a series of gravity flows to a bank of carding or weaving machines in the textile industry. The particular type of work station most suitable to an industry depends upon the terminus of the process or of the operation. The work station may consist of a single operator on one or several machines, or of a machine operated by one or several workers.

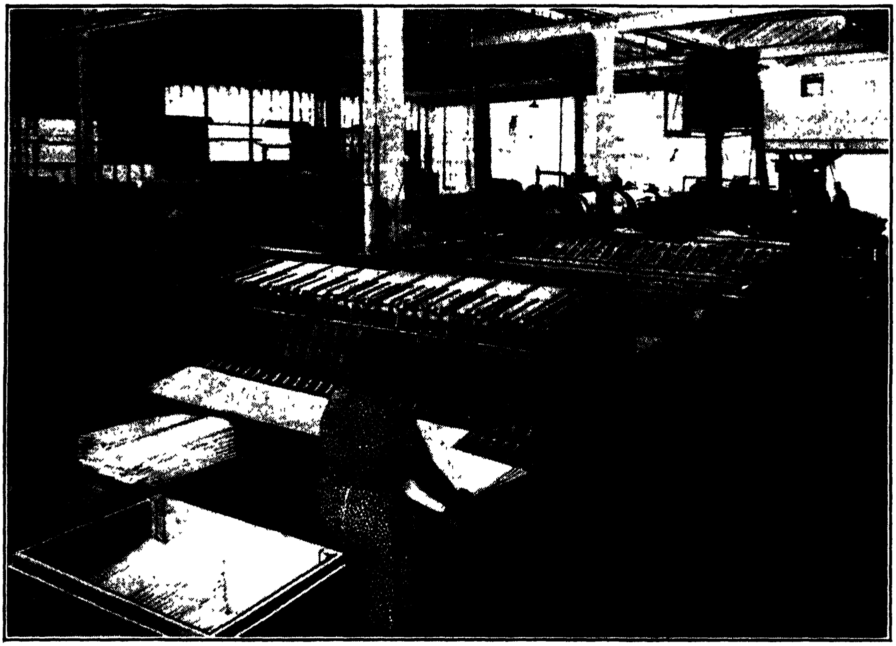


FIG. 16. *Machine crew in a commercial laundry.* Four workers operate a flatwork ironer equipped with an automatic spreader (on feed end in background) and with an automatic folder (on delivery end in foreground). (*Courtesy of The American Laundry Machinery Company, Cincinnati.*)

The Assembly Station

In assembly work, as differentiated from machining or fabricating work, the same distinction holds for a work center, namely, that either the worker or the integrated group of assembly workers forms the indivisible space unit for the plant layout. Such a group, consisting of nine work stations arranged radially on an assembly floor, all served by a single full-swiveling jib crane, is shown in Figure 17. The assembly line is arranged around a circle to enable the nine operators to make common use of a single crane. The units are assembled on skids so that the heavy bases, as well as the finished assembly, can be moved to and from the assembly stations by means of power lift trucks.

Combination of Processing and Assembly

A combination group which performs both processing and assembly work is shown in Figure 18. In this layout the three operators at the left use individual

FIG. 17. *Nine work stations served by a rotating crane.* These stations are arranged radially as a production unit to make common use of a full-swiveling jib crane. Each of the operators can use the crane without interference. The arrangement saves floor space and uses minimum equipment. The heavy assembly is mounted on truck skids so that it can be moved to the next operation without extra handling. (*Courtesy of Westinghouse Electric Corporation, Pittsburgh.*)

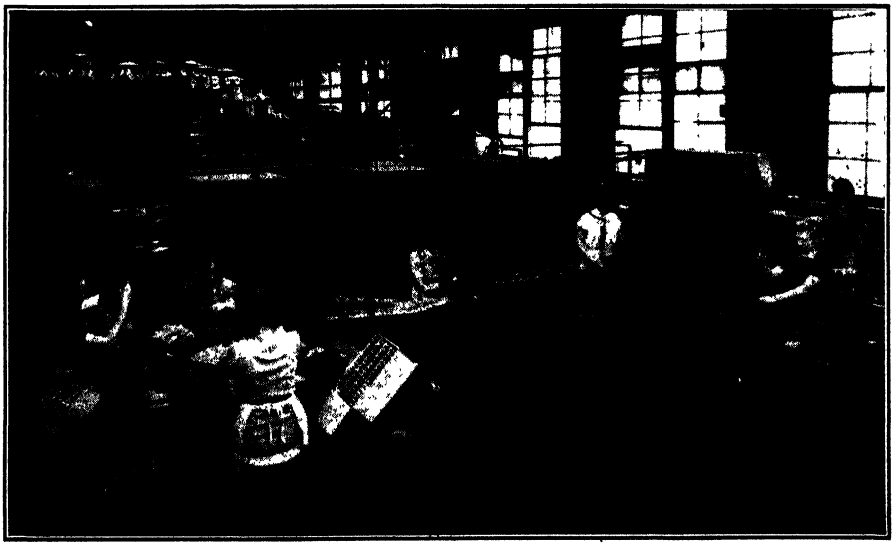


FIG. 18. *Combination processing and assembly work station* in an assembly line powered by suspended nut-drivers and serviced by gravity roller conveyors.

power nut-drivers suspended from a common framework, and they dispatch their assembled units on a common roller conveyor to a fourth operator in the center of the layout for further processing. The work then advances to the fifth and sixth operators on the right for completion. In this case, the uninterrupted cycle of operations comprises the entire group of six operators. The entire group, in turn, constitutes an individual production unit, or work center.

4. THE SIZE AND LOCATION OF PLANT DEPARTMENTS

Two Types of Work Centers

The work center, as already indicated, is the smallest indivisible unit of production, and consists of two basic types, namely:

1. **The work station,** being the floor area occupied by a single worker operating one or more machines. This area includes floor space for the work bench, racks, conveyors, skids, tote pans, and a portion of the side aisle on which the work station borders.
2. **The machine crew,** being the floor area occupied by the entire crew of machine loaders, machine operators, and machine unloaders required as a team of attendants to operate a single machine in certain processes. This area of course includes the floor space occupied by all the auxiliary equipment, such as work benches, racks, trucks, conveyors, and aisle space, needed next to the machine.

The Plant Department

In locating these production centers, the layout is planned to provide the shortest distances and least handling in moving the materials from one production center to the other, at the same time permitting continuous processing between the centers. A succession or group of production centers form the basis for a plant department. The idea behind the establishment of a department is to place a practical number of production centers under the jurisdiction of a foreman.

In some plants where the department is kept small, thus requiring fewer departmental supervisors, it is not unusual to find a number of departments performing the same type of work, all more or less on a competitive basis from the standpoint of comparable costs and efficiencies. The policy in other plants is to favor large departments with considerably more supervision than is required in small departments.

Regardless of the size of the department, the output capacity in the different departments has to be kept equalized to avoid bottlenecks in production. Thus, if the winding department in a motor factory cannot keep up with the flow of rotors from another department, the winding department becomes the department that slows down the output of perhaps the entire production line. It is a function of plant layout to balance the capacities of the productive departments within a plant.

Departmental boundaries are seldom considered fixed like the walls on a factory floor. The addition of new machines in a department increases the amount of floor area required. Or a department may become permanently idle. In an existing building, the departmental boundaries are shifted by expanding or contracting adjacent departments. Operations are sometimes transferred from one department to another to help balance the departments, improve quality control, reduce material handling, simplify supervision, eliminate idle capacity, make room for new operations, etc.

Three Types of Plant Departments

The various departments in a plant fall into three general classifications:

1. **Processing departments.** These are the subdivisions of the "shop" proper, wherein all machining, processing, assembly, and packaging work is performed.
2. **Service departments.** These constitute the facilities provided to keep the processing departments in operation without interruption. Such facilities consist of receiving and shipping areas, stockrooms, toolrooms, repair shops, testing areas, plant utilities, employee rest rooms, cafeterias, first-aid rooms, etc.
3. **Office departments.** These offices may include administrative, sales, engineering, accounting, production control, personnel relations, training departments, and such areas as lecture rooms, display rooms, reception rooms, etc.

The technique for laying out the processing departments forms the subject matter of Part 2, whereas the service departments and office departments are covered in detail in Part 3.

5. STRAIGHT-LINE FLOW IN MASS PRODUCTION

Advent of Production Lines

The advantages of large-scale production, which were first revealed in World War I, have since led to a marked increase in the capacity of plants per square foot of floor space. It has also encouraged the consolidation of several plants under one roof, as illustrated in Figure 19, showing a double-deck assembly system at the Chevrolet plant of the General Motors Corporation. In many plants this expansion in size has tended to lengthen the flow of materials within the plant.

In an effort to avoid the additional cost of transporting materials over longer routes of travel during processing, production "lines" are often set up, when economically justified, to bring together in one department all the various units of machinery and equipment needed to perform all the work on one kind of unit, such as a motor shaft, a gear, etc. In a "line" production layout, the necessary machines of different kinds, such as punch presses, turret lathes, drill presses, etc., are placed along the path of travel followed by the flow of the piece part, thus permitting each machine operation to be performed in proper sequence as the product progresses down the "line."

The arrangement of work stations in the proper sequence of operations eliminates much of the material handling from one work station to the other and often permits the installation of chutes, conveyors, cranes, or other devices to mechanically transport the work from one operator to the next (see Figure 20).

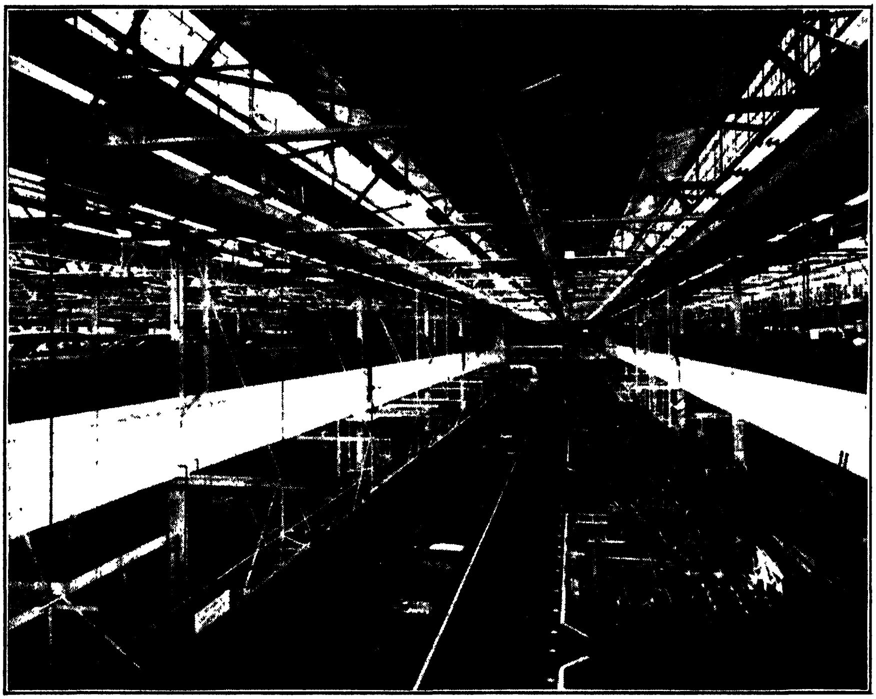


FIG. 19. *Double-deck assembly system* at the Chevrolet plant of the General Motors Corporation, Flint, Mich. On the lower level, chassis are proceeding toward the body-drop, while on the upper level a simultaneous flow of bodies progresses toward the same spot. In this way the two side bays function as feeders to the operations in the main bay. (*Courtesy of Albert Kahn Associated Architects and Engineers, Detroit.*)

In order to avoid bottlenecks along this flow of production, the output capacities of the successive machines along the production line must be kept in proper balance.

An Actual Straight-Line Layout

The layout of a complete production line (on a straight-line basis) for the manufacture of fractional-horsepower electric motors is shown in Figure 21. The line is bisected by an aisle, with operations carried on simultaneously on both sides of the aisle. The production line in the first strip continues through the second strip and ends in the third strip, with both sides of the aisle shown in each strip. The flow of production through the line is sectionalized into successive operating groups in the following order:

groups the equipment on a functional basis. Thus, all machines of one type, such as screw machines (see Figure 22) are grouped together in one department, all punch presses in another department, etc. Although these machine departments may be set up advantageously as "feeders" to assembly lines in mass-production work, they are usually more suitable for small job-lot production involving a different set or sequence of operations with each succeeding lot.

FIG. 22. *Functional type of production.* Department of hand screw-machines for processing small turned parts. Functional processing disregards the product flow and groups all machines of one type, as shown here, in one department.

Often a combination of the two main types of production layouts, straight-line and functional, exists in the same plant to secure the advantages of each type and provide greater flexibility in the production of diversified lines of units.

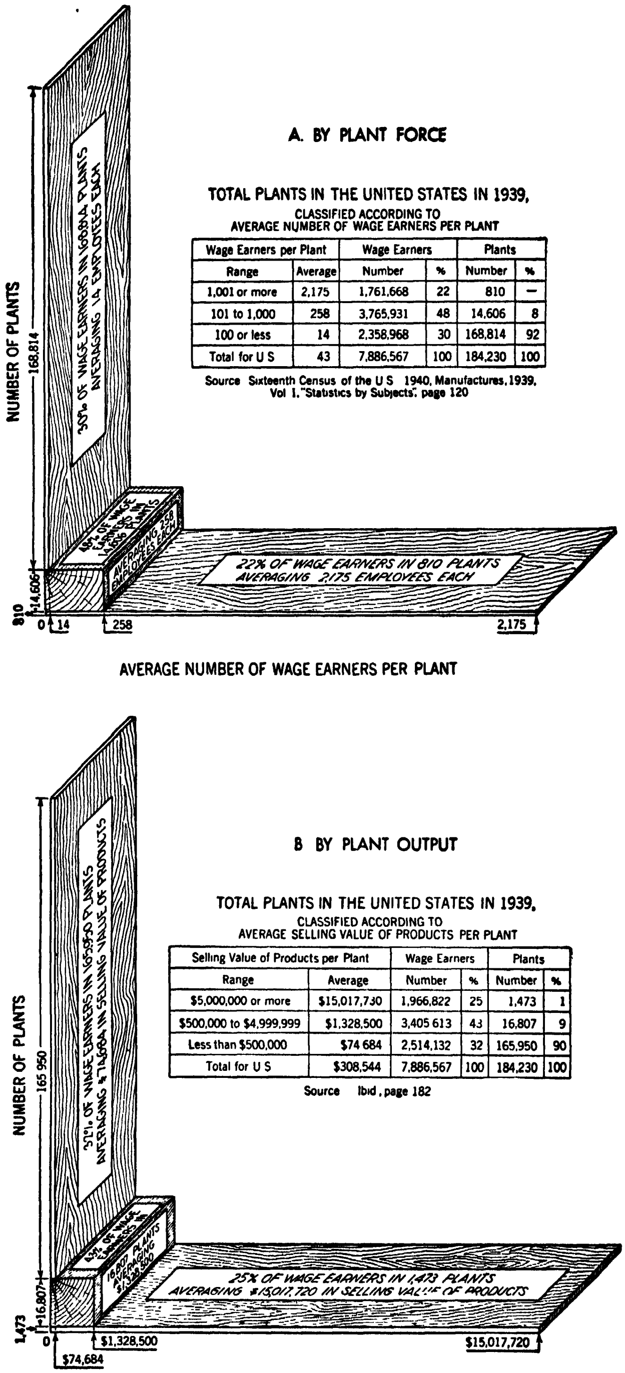
6. THE SIZE PATTERN OF MANUFACTURING PLANTS

Two Extreme Conditions in the Size Pattern

The present trend towards decentralization of large plants into small plants brings up the question of the relative sizes of plants in the various manufacturing industries in this country. In 1939, the last year that was free of a major influence from the demands of World War II, there were 184,230 manufacturing establishments in this country (see upper section of Figure 23). Of these establishments, 92 percent employed 100 or less wage earners each, and these small plants employed only 30 percent of all the wage earners.

Two extreme conditions prevail in the size pattern of manufacturing plants in this country, as illustrated in Figure 23:

1. A large number of small plants employ 30 percent of all the wage earners.
2. An infinitesimally small number of large plants employ 22 percent of all the wage earners.



TOTAL PLANTS IN THE UNITED STATES IN 1939,
CLASSIFIED ACCORDING TO
AVERAGE NUMBER OF WAGE EARNERS PER PLANT

Wage Earners per Plant		Wage Earners		Plants	
Range	Average	Number	%	Number	%
1,001 or more	2,175	1,761,668	22	810	—
101 to 1,000	258	3,765,931	48	14,606	8
100 or less	14	2,358,968	30	168,814	92
Total for U S	43	7,886,567	100	184,230	100

Source Sixteenth Census of the U S 1940, Manufactures, 1939, Vol I, "Statistics by Subjects", page 120

TOTAL PLANTS IN THE UNITED STATES IN 1939,
CLASSIFIED ACCORDING TO
AVERAGE SELLING VALUE OF PRODUCTS PER PLANT

Selling Value of Products per Plant		Wage Earners		Plants	
Range	Average	Number	%	Number	%
$5,000,000 or more	$15,017,730	1,966,822	25	1,473	1
$500,000 to $4,999,999	$1,328,500	3,405 613	43	16,807	9
Less than $500,000	$74 684	2,514,132	32	165,950	90
Total for U S	$308,544	7,886,567	100	184,230	100

Source Ibid, page 182

FIG. 23. *Size of manufacturing establishments.* Total plants in the United States, 1939, classified according to plant force and plant output. Note the similarity of the size pattern in the two classifications.

These two groups combined account for 52 percent of the total working force in manufacturing industries. The remaining 48 percent of the force work in plants ranging in size from 101 to 1,000 wage earners.

Plant Layout in Small Plants

Plant layout problems in plants employing 100 or less wage earners and representing 92 percent of all plants occur as frequently as they do in larger plants. The efficiency of production technique is an ever-present problem in small plants as in large plants, but it does not involve the interrelationship of several co-ordinated departments existing in the larger establishments. In analyzing departmental problems in the plants employing over 100 wage earners, the problems of the 168,814 smaller plants are incidentally included. Likewise, in analyzing plant layout in terms of plant departments, the 810 plants employing over 1,000 wage earners each meet on common ground in this book with the 14,606 medium-size plants employing between 100 and 1,000 workers.

Annual Volume of Business

In classifying the plants in this country according to the volume of business done in a year, as shown in the lower section of Figure 23, we find virtually the same size pattern as we did in terms of the number of wage earners:

1. A large number of small plants do 32 percent of all the manufacturing business.
2. A minute number of large plants account for 25 percent of the total business.

Between these two extremes is the group of 16,807 medium-sized plants, each with a selling value of annual output ranging from $500,000 to $5,000,000, supplying 43 percent of the national output. In round figures, then, almost one-half the manufacturing activity in this country is carried on in some 15,000 medium-sized plants averaging 250 wage earners each, and with a sales volume of slightly more than $100,000 a month.

7. THE SCOPE OF A PLANT LAYOUT PROJECT

Where the Project Begins and Ends

The question is often asked, "Where does a plant layout project begin, and where does it end?" To attempt to give a definite answer to this question would be as asinine as to venture an outright reply to the equally perplexing query, "How high is up?" For who knows where "high" begins and ends, assuming it does either or both?

In more specific terms, a plant layout idea can begin as a dream in the mind of an executive who visualizes the advantages of a new plant or of a new arrangement in an existing plant. A plant layout problem may be thrust upon a plant layout engineer, or he may explore current manufacturing activity in the quest of an improvement. In either situation, the approach to the problem follows along parallel lines.

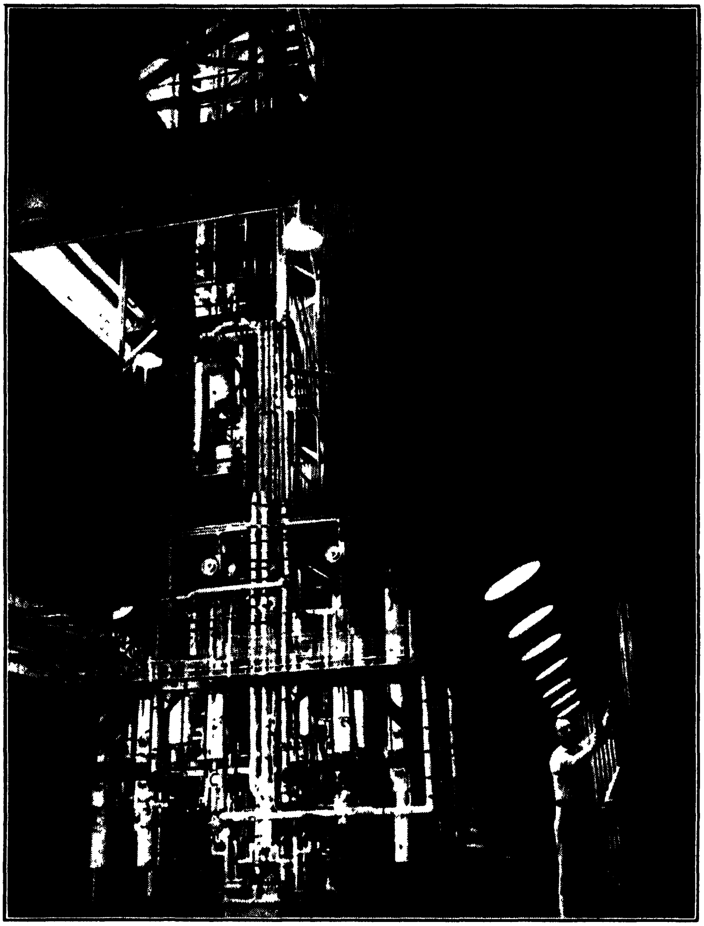


FIG. 24. *Pilot plant for designing refineries.* Solexol Process pilot plant of the M. W. Kellogg Company, Jersey City, N. J. This is the plant on which tests are made to provide data for the design of commercial plants for the refining of marine, vegetable, and animal oils. A selective extraction of as much material as desired can be achieved merely by raising the temperature and bringing the oil-propane mixture into equilibrium.

A Recurrent Problem

Where those lines end, that is, where a layout project is considered completed, is as undefinable as the starting point of the project. Plant layout is a recurrent problem. Plant layout designs in progressive enterprises, as already pointed out, seldom remain fixed, and are normally considered in a continual state of flux. The existence of the need of plant layout revisions may therefore be said to terminate when a shop becomes inactive. The development of a given project may also be considered as having reached completion, not after the project has been completely installed, but when the installation is dismantled and retired.

The point of immediate concern here is the tangible starting point, or realistic beginning, of a plant layout undertaking, after the preliminary embryonic idea has been conceived. Once the plant layout engineer has been assigned to undertake a specific plant layout study, he begins by mapping out his plan of attack. He outlines the steps he will take in surveying the physical circumstances surrounding the project and in checking the information concerning the existing layout.

CHAPTER IV

Basis for Designing a Plant Layout

"Our knowledge is the amassed thought and experience of innumerable minds." Ralph Waldo Emerson.

1. GROUNDWORK PRECEDING THE LAYOUT DEVELOPMENT

Purpose of the Layout

A plant layout project may range from the rearrangement of a single work station to the development of a network of feeder plants located in different states. Before a plant layout is undertaken it is first necessary to justify the need for one, and this can best be done through the medium of a preliminary statistical analysis. Several alternatives present themselves before a new layout can be seriously considered.

If the purpose of the layout is to reduce material-handling costs or to expedite the flow of work in process, the cost of changing the layout and of installing new equipment must be compared with the end results before much effort is spent in actually developing a new layout. If the layout is intended to provide new or additional productive capacity, the several means of obtaining this added capacity without altering the present structure or perhaps erecting a new one must be thoroughly explored before deciding on a new layout. For example, it may be more economical or expedient to increase the number of shifts in the existing plant or to subcontract the work to another plant.

Preliminary Estimates of Returns on Investment

In order to weigh these alternatives intelligently and factually, an analysis has to be made of cost and production statistics under each plan. The volume of business involved must be estimated from a combination of known facts and projected trends. The relative manufacturing cost under each plan has to be estimated by reconstructing known costs and estimating new cost factors. All of this calculation calls for a comprehensive analysis of existing statistical trends in costs, available machine capacity, labor efficiency, market outlook, business cycle, and the company's position in the particular industry involved. An actual analysis of production trends and forecasts is shown in Figure 25 for a foundry contemplating the addition of two new lines of products in an effort to recapture a shrinkage in volume at the close of World War II.

When preliminary estimates from selected alternatives indicate a sound justification for a new layout, then the suitable type of layout to be developed must be selected. In factory layout the difference between a continuous process and an assembly process becomes significant at the outset. Plant layout problems wherein the product can be flowed by gravity or pumps differ materially from those in which the work must be moved by hand, crane, truck, or conveyor. Operations involving heavy machinery receive first consideration in designing layouts. Repetitive operations on standardized products must also be distinguished at the start from unlike operations on non-standard products.

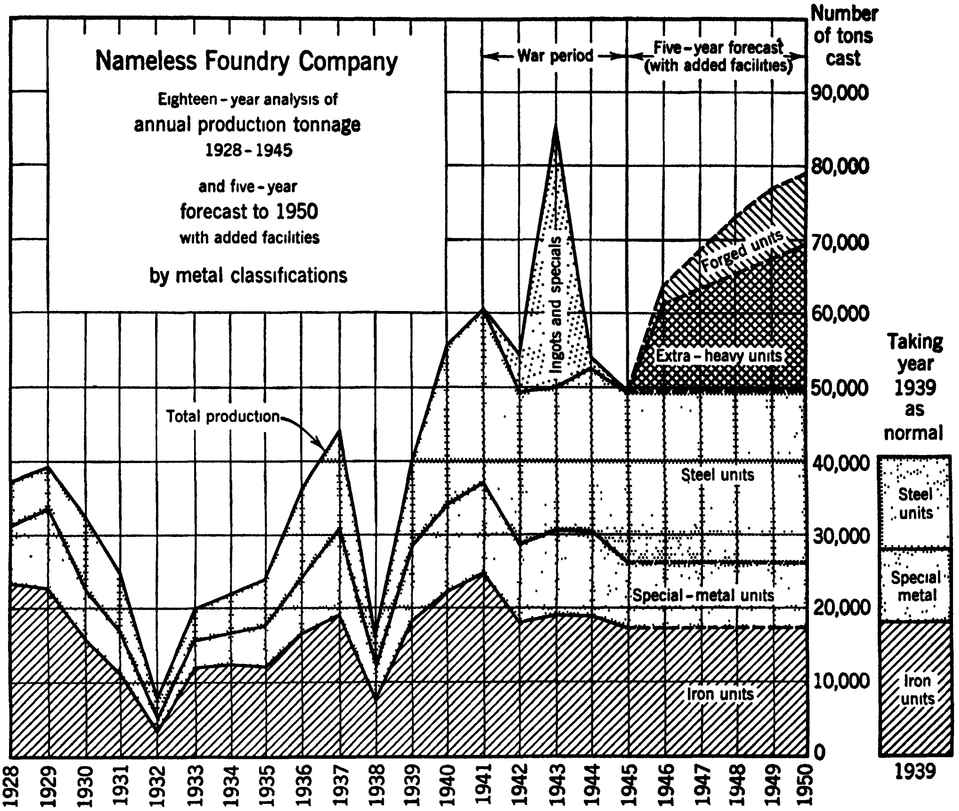


FIG. 25. *Production trends and forecasts.* Actual analysis of annual production tonnage over an 18-year period in a foundry company. Note the typical business-cycle dips in 1932 and 1938, and the war-production bulge in the five years from 1940 through 1944. The 5-year forecast levels off existing product lines at the 1945 volume and introduces two new lines in an effort to regain the wartime production peak.

Selecting the Tentative Type of Layout

Although many of these fundamental factors can be determined readily by a competent plant layout engineer without the need of supporting statistics, the fact must not be overlooked that, at this stage of the plan, consideration is limited to the broad factors influencing the selection of an appropriate type of layout. The point of actually developing the layout has not yet been reached. It does not require much basic data to determine whether the product is light or heavy, or whether it is to be moved by truck, crane, or conveyor, or how much heavy machinery is involved. Nor does it necessitate much research to ascertain if women workers are to be employed, or whether to manufacture on a straight-line or a functional basis, or on both. Selecting the tentative type of layout to use is but a preliminary step to give form and shape to the layout design. This type of planning does not determine the number of machines, cranes, conveyors, work stations, aisles, storerooms, departments, etc., to be provided for in the project, but it does set up a guide in developing the layout as described in later chapters.

2. PRELIMINARY SURVEY THROUGH STATISTICAL ANALYSIS

Statistical Records of Reference

Preliminary analyses of this sort are obtained by a careful scrutiny of statistical records providing dependable reference to such data as:

1. Sales volume of each line of products.
2. Manufacturing labor and expense by control cost accounts.
3. Net allowed hours and machine loads.
4. Number of employees on the payroll.
5. Amount invested in fixed assets and inventories.
6. Inventory of machine tools and handling equipment.
7. Organization charts.
8. Plant layout drawings.
9. Backlog of unfilled orders.
10. Past history of production activity.
11. Quality of product.
12. Percentage of rejects.
13. Changes in product designs.

Summary of Survey

Final plant layout designs are based directly upon these investigations and analyses and do not result simply from a mere fitting together of templates. Equipped with this advance information, the plant layout engineer inquires into the layout project being contemplated and reviews on the premises all plant facilities for handling, processing, dispatching, and storing raw materials; work in process; and finished products. He analyzes bottlenecks, inefficient flows, percentage of rejects, and operator efficiencies. He holds meetings with the key men in the plant in order to appraise properly the circumstances calling for a new plant layout. A summary of this survey is then written, with supporting statistics attached.

This survey should be conducted by experienced plant layout engineers whose training enables them to recognize the relative importance of a project in its initial stages. It is their function, while making a preliminary survey on the premises, to map out the amount of work to be done subsequently on the premises and to set up the contacts through whom the actual layout development will operate. This is the stage at which contacts with other departments, such as sales, accounting, production, and engineering, are established for the purpose of gathering the necessary statistics. At this stage also statistics are gathered on new process developments that have a direct bearing on trends in manufacturing methods, such as plastics, powder metallurgy, and electronics, which may ultimately affect the plant layout design.

Following Up the Survey

The survey work at this stage does not end with the submission of the preliminary report on a project. When not engaged on special projects, plant layout engineers circulate continually around the various departments of the plant, as well as through outside plants, in search of new ideas. In the course of their travels these engineers keep looking for incipient layout problems which, by reason of their specialized aptitude, they can recognize and appraise long before the problems develop into emergency requirements. In the meantime, while awaiting action on the survey, they keep in close contact with the operating departments and the plant management, to assist in working out present and future plans for new operations, transferring manufacturing activities to other departments or plants, farming out work to outside subcontractors, acquiring new enterprises, and keeping the company abreast of new trends in the flow of work through production and assembly lines.

3. INFORMATION GATHERED FOR TENTATIVE LAYOUT PLANS

Business Potentials of the Layout Project

Only too often a comprehensive set of layout plans drawn up from fanciful thinking on the part of overzealous production men and independent of the relevant sales potentials and resulting profits, carries enough plausible weight to gain direct approval. That is usually the reason why, as soon as a plant starts making a profit, it often dissipates it unwisely on plant expansion without duly exploring the sales and profit angles covering the life span of the new investment involved.

Preliminary Analysis of the Project

The actual work of developing a layout project should not begin until the plant layout engineers surveying the project have visited the premises where the new layout is contemplated, then submitted their preliminary survey of the problem, appraised the project, and estimated the amount of work required to prepare the design. Through the medium of the statistics compiled for the preliminary survey, the plant layout engineers determine the labor hours, volume of output, and number of operators involved in the new layout. In doing this, they contact the various sections and departments at the plant to secure:

1. Proper manufacturing methods
2. Time values
3. Cost analyses
4. Quality control requirements
5. Lists of works equipment
6. Production planning
7. Tooling requirements
8. Power loads
9. Record of existing service facilities

Process Flow Chart

This information is assembled into an integrated plan and summarized into a tentative process flow chart. In making a process flow chart, suggestions should be solicited from those working directly on the operation. Some of the most valuable suggestions come from this source. When the operators are given an opportunity to discuss proposed rearrangements with their foremen, they often bring up valuable suggestions for making practical improvements. When these are considered in line with the main plan, many good ideas can usually be incorporated.

Tentative Plant Layouts

Material-handling facilities are then brought into the picture, inspection points and dispatch stations are added where needed, and storerooms are laid out to handle the projected output. Tentative plant layouts are prepared and revised as needed until a final layout meeting the requirements of the project has been developed. Work-station layouts supply the basis for operation and time elements for calculating time values in accommodating the output capacity contained in the final plant layout decided upon.

Supporting Statistics

While a tentative layout is being drawn up from the data supplied in the survey, additional and more specific information has to be gathered on the plant premises. This information consists principally of:

1. Building dimensions and structural characteristics
2. Location of existing machinery and equipment
3. Lists of tools
4. Lighting and heating utilities
5. Storage facilities
6. Material-handling equipment
7. Sanitation facilities
8. Power plant
9. Office buildings
10. Utilization of present capacity
11. Tentative spots for inspection points

Pertinent Shop Information

Supplementing these cold statistics, the plant layout engineers require data on more pertinent items, such as:

1. The existing plant force
2. Product design
3. Processing and assembly operations
4. Operator efficiencies
5. Manufacturing methods
6. Production routing

Experience has shown that young student engineers are more successful in securing pertinent information than are more mature engineers. The young engineer places more energy in seeking detail information, is normally more inquisitive, and arouses less suspicion in the minds of operators and foremen than does the older engineer. A combination of experienced engineers and student engineers appears to be the ideal approach to the problem of gathering information in the works proper.

Other information gathered in the shop includes:

1. Time lost at work stations due to improper layout
2. Amount and condition of stocks carried in process and in storerooms
3. Efficiency of shop controls over:
   a. Production schedules
   b. Machine setups
   c. Material scrap
   d. Percentage of rejects

Testing Alternative Layouts

In connection with the need for making more than one tentative layout for the same project, H. K. Ferguson of the H. K. Ferguson Company, a leading firm of plant construction engineers, Cleveland, Ohio, stated in an address before the American Management Association, November 15, 1939, in Chicago:

> My own high mark to date is the making and testing of 34 alternate layouts for one plant, before arriving at the one, and only one, extremely simple and clean-cut arrangement which most nearly harmonized the ideal and the practicable layout in all particulars.*

In describing the automobile-frame plant of the A. O. Smith Corporation in Milwaukee, Professor R. M. Barnes states that it took 5 years and $8,000,000 to build the plant, and quotes L. R. Smith, president of the company, in these words: "Ten times the plant was built on paper at a cost of $1,500,000 for pencil roughs." †

Cost of the Survey

To the uninitiated in the fields of plant layout and statistical analysis, this may seem like a large order of information just to determine what plan to select before making a plant layout in final form. When it is realized how easily a project running into thousands, hundreds of thousands, and even millions of dollars may turn out to be a "white elephant," the expenditure of the time and effort required to gather and digest this information represents but a fraction of the cost of the project itself.

---

* R. H. Lansburgh and W. R. Spriegel, *Industrial Management,* Third Edition, John Wiley & Sons, 1940, p. 135.

† R. M. Barnes, *Industrial Engineering and Management,* First Edition, McGraw-Hill Book Co., 1931, p. 45.

Furthermore, the cost of this information is more than compensated for by the time and effort saved after the project gets underway through less confusion in reconciling controversial suppositions. This is not counting the possible saving that accrues from discarding "white elephant" plans before they reach the stage of execution.

4. INTANGIBLE FACTORS UNDERLYING A LAYOUT PROJECT

Limited Objectives Commonly Found

In many manufacturing organizations, the plant layout department is nothing more than a section of the plant engineering or the production departments. As a result of this isolation from the general administrative organization, plant layout work often begins and ends with only two objectives in mind, namely:

1. Improved utilization of existing facilities.
2. Finding reasons for buying new equipment.

In the more progressive companies where engineering technique has been applied to the field of top management in seeking additional markets for the products or an expansion of volume by the addition of products, plant layout engineering has been emancipated from a perfunctory role and placed in close contact with market development, both with direct access to the general manager.

Marketing Cost

Whereas plant layout is concerned primarily with the flow of the product through the production line, marketing follows the flow from the end of the production line, through the company's customers, and into the consumers' hands. Very few companies know the full cost of marketing their products from the time the products leave the factory until they are purchased by the ultimate consumers. The cost of marketing the product is often as much as the cost of manufacturing it. When one-half of the consumer's dollar for a company's products goes for the marketing cost, only the other half goes to the manufacturer. Furthermore, when one-half of the manufacturer's share goes for material handling within the plant itself, only one-quarter of the consumer's dollar remains for the payment of productive manufacturing operations.

In a competitive economy, it is the consumer's entire dollar that causes him to decide which product to buy. The fact that only one-half of his dollar goes to the manufacturer is of no concern to the consumer. But the fact that the consumer pays twice as much for the product as it costs to manufacture it becomes of immediate concern to the manufacturer in his struggle to attract the consumer's dollar from competitive products. When a company distributes its line of products through a national sales agency, the company cannot readily adapt its product design and production facilities to market demand unless it maintains its own force of market analysts and budgets its plant capacity to scientifically projected sales requirements.

Sale of Plant Capacity

In the final analysis, that which a manufacturing organization has to sell is plant capacity, either for existing or new products. Through plant layout, that capacity must be kept related to market demand if the plant is to make the most profitable use of its capacity. Through sales forecasts and budgets, the company develops its marketing program over a number of years. The relationship between the sales forecast and the output capacity is reciprocal. The one determines the possibilities of the other according to the strategy employed by the management in exploring both the market and the plant facilities. In acquiring new products, additional markets, etc., the management is compelled to focus its product engineering and manufacturing capacity first in one product field and then in another, shifting its spotlight in pursuit of market demand.

Changes in Sales Requirements

Each engineering change in a product affects plant layout, and each change in sales requirements affects scheduling, routing, and the output capacity of a given layout. The acceptance of special orders definitely upsets the best-planned production schedules and often seriously paralyzes the output capacity of the plant. Sales promotion, market potentials, product development, company expansion, etc., are all dependent on plant facilities, and these in turn are all determined and kept reconciled to changing requirements through alert plant layout engineering. For these reasons, an engineering-minded management maintains marketing and plant layout engineering in close contact in order to project sales for the entire plant capacity instead of for products which it may not have the capacity to manufacture at the right time, or which may never permit a maximum utilization of available plant capacity.

Evaluation of Alternative Plans

A plant layout that begins by simply obtaining a production forecast from the management is seldom more than a plan to reshuffle machinery and equipment in an attempt to meet a foregone volume, often with the injudicious addition of floor space and new equipment. On the other hand, a layout that begins after a number of preliminary alternative plans have been roughed out and properly evaluated, to provide the management with a choice of output possibilities before the sales program is decided upon, offers a sounder basis upon which management can forge ahead with confidence in a competitive economy.

5. CHECK LISTS OF ADVANCE DATA FOR THE PROJECT

Outline of 18 Steps

The initial steps taken by the plant layout engineer in "sizing up" the situation of a layout project are enumerated below for a normal revision project in a manufacturing establishment, regardless of size. In considering these steps, however, it must be borne in mind that *not every step* applies in every layout study, *or in any specific project* for that matter, nor do the steps necessarily *follow the sequence* given here. The 18 steps outlined below are a list of points not to be overlooked rather than a cut-and-dried program to be adhered to in outlining a plan of attack.

CHECK LIST OF ADVANCE DATA ON PRODUCTION LOADS

1. Study the different **types** of products to be manufactured.
2. Study the individual **designs** of these products.
3. Determine the parts or materials that are **interchangeable** or common.
4. Ascertain the probable **life** of the separate product designs.
5. Analyze past **activity** and present loading.
6. Secure projected **loading** in writing.
7. Break down the projected loading into component **parts.**
8. Study the **feeder-section** connections contemplated.
9. Analyze the problems of **material handling** and transportation.
10. Review the **operation file** with the time-study or methods engineer. Ascertain the wage rates, earnings, and operating efficiency of the plant force, overtime, and setups. Secure the responsible supervisor's recommendations.
11. Make a thorough study of the **storerooms** and stockrooms. Secure full information concerning the present practice of holding stock. Determine the present and contemplated investment in raw materials, work in process, and finished stock. Check these figures against the contemplated production loading.
12. Break down the projected loading of component parts into **operation elements.**
13. Convert the operation elements into **operations.**
14. Route the operations into their proper **sequence.**
15. **Balance** the operations.
16. Align the operations on **flow charts.**
17. Study the flow charts for **bottlenecks,** trends in processing, centralization possibilities, facility requirements, and surplus capacities at work stations.
18. Make a comprehensive check of major **tools** available to determine:
    a. The operating **condition** of the tools,
    b. The quantity of tools **on order,** by types,
    c. The contemplated **loading** of the production equipment,
    d. The types of **machine tools** to which the planned operations will be dispatched,
    e. The types of **small tools,** jigs, and fixtures needed, and
    f. The **drive medium** of the machine tools selected.

Buildings and Equipment

When the proposed layout is to be housed in existing buildings and is to utilize existing plant facilities, the following data on existing buildings and equipment should also be compiled in advance of undertaking the development of the revised layout.

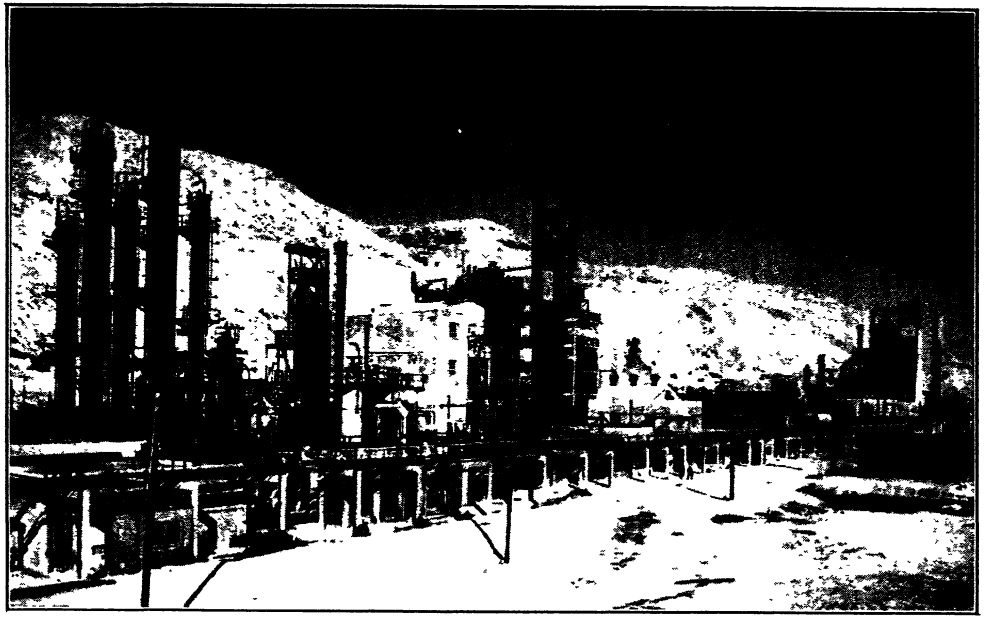
CHECK LIST OF ADVANCE DATA ON EXISTING FACILITIES

1. Prepare **machine tool layout information** forms on all machine tools and production equipment.
2. Compile the sizes and shapes of all **workbenches,** racks, and other furniture and fixtures on the existing layout.

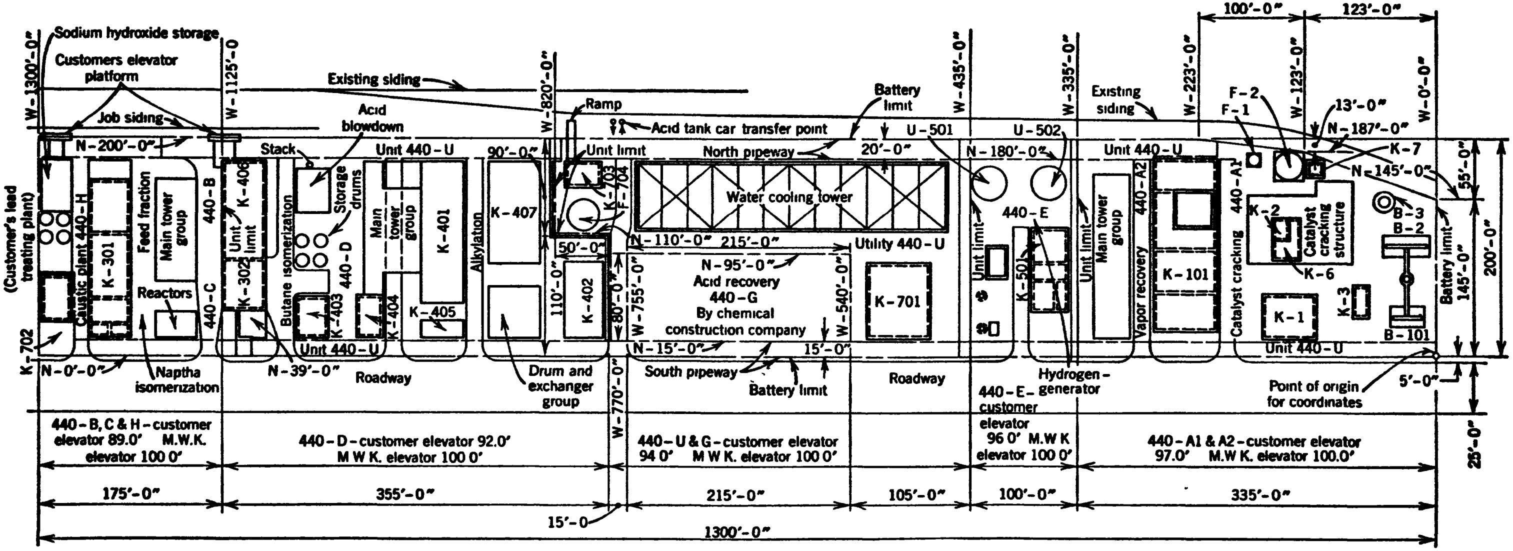
3. Check building **openings for aisles,** entrances, and exits.
4. Prepare a floor plan showing all **floor obstructions** such as:
   a. **Water fountains,** switch boxes, lighting panels,
   b. Sprinkler risers, **pipelines** for gas, water, air, and steam, **drainage** facilities, and manholes,
   c. Fire **hose reels** and extinguishers,
   d. Fire and **police boxes,** and
   e. Industrial and broad-gauge **trackage.**
5. **Floor loads** and weight of work in process. Also allowable loads.
6. **Roof** construction and overhead clearances.
7. **Office** facilities.
8. Check the floor blanks for the accuracy of **building dimensions** and location of aisles, stairways, and elevators.
9. **Foundations** for machinery.
10. **Storerooms,** tool cribs, and test facilities.
11. **Window** arrangement.
12. Location of **noisy equipment** such as grinders, saws, punch presses, and drop hammers.
13. Conditions of **lighting,** heating, sanitation, ventilation, and safety.

No attempt has been made in the list above to illustrate specific applications in any particular plant or in a standard sequence. These items cover principles applicable in part or in whole to any plant, as warranted by the conditions related to a project. No uniformity exists in the emphasis, sequence, or number of principles applied in individual projects. Experience and judgment are the only guides for measuring the degree of refinement required in compiling and utilizing the principles enumerated in this check list.

An example of a layout designed to make an addition to an existing oil refinery is shown in Figure 26. Units were added to this plant of the Utah Oil Company to permit the production of high-octane aviation gasoline. As described on the layout, the additional units were arranged in a straight-line relationship, starting with the catalyst cracking structure, for economy in piping. Without a thorough advance gathering of data on existing facilities and a subsequent co-ordination of the projected plans with these facilities, it is safe to conclude that this layout would never have reached the stage of actual installation as made by the M. W. Kellogg Company.



A. General view of high-octane addition. The basic unit in this arrangement is the fluid-catalyst cracking structure at the extreme right. Note elevated pipeways permitting easy access to all units.



B. Layout of the same high-octane addition. These units were installed in the existing refinery to permit the production of high-octane aviation gasoline. The principal units were spaced far enough apart to satisfy safety requirements. For economy in piping, the units were arranged in a straight-line relationship from right to left.

FIG. 26. *Expansion of an oil refinery.* Addition of high-octane units installed in the existing refinery of the Utah Oil Company, Salt Lake City, by the M. W. Kellogg Company, Jersey City.

CHAPTER V

Benchmarks Used in Plant Layout Work

1. PLOT PLANS, AREA DIAGRAMS, AND PROCESS CHARTS

Plot Plans

If the project involves more than one building on the same premises, the starting point in laying out the project is a plot plan of the entire plant property. Such a plan is illustrated in Figures 27*A* and *B* for a lamp works comprising 11 separate buildings. The plan shows the various buildings already in existence, property lines, plant yards, roadways, railroad sidings, and outside facilities, such as fire hose and plugs, outdoor cranes, tanks, pump houses, scrap bins, and storage areas.

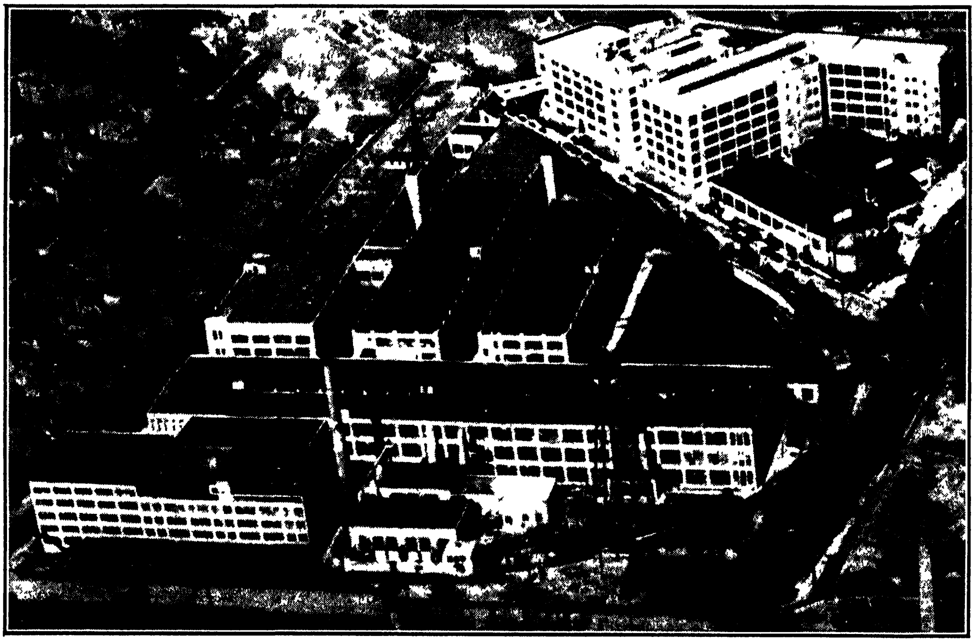


FIG. 27*A*. *Photograph of a lamp works consisting of 11 separate buildings* intersected by a public street and inclosed by railroad sidings. (*Courtesy of Westinghouse Electric Corporation, Bloomfield, N. J.*)

The information concerning each building is confined to the number of the building, its dimensions, number of stories, floor elevation in feet, stairways, and elevators.

For a modern manufacturing plant consisting of only one manufacturing building, a plot plan showing the complete site development is as necessary as it is for a multi-building establishment. A typical plot plan for a plant of this type is shown in Figure 28. If the over-all arrangement of the plot is planned before

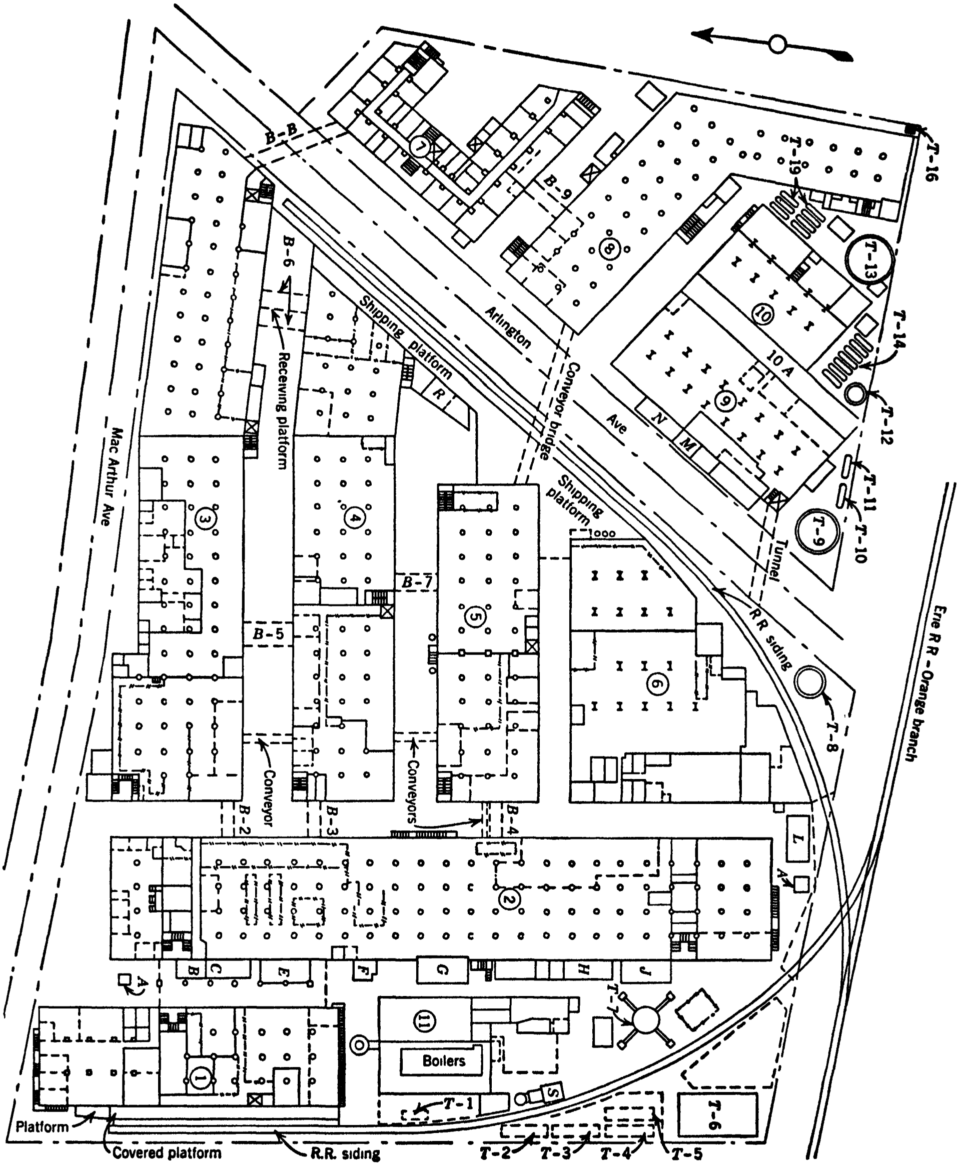


FIG. 27*B*. *Plot plan of the same lamp works,* showing the network of overhead bridges and underground tunnels linking the 11 buildings into a unified pattern of detached floor layouts.

any of the structural units are built, much expense and delay can be avoided later as the buildings come into being. Management can thus plan its investments in plant construction and expansion with greater economy and utilization than by piecemeal planning.

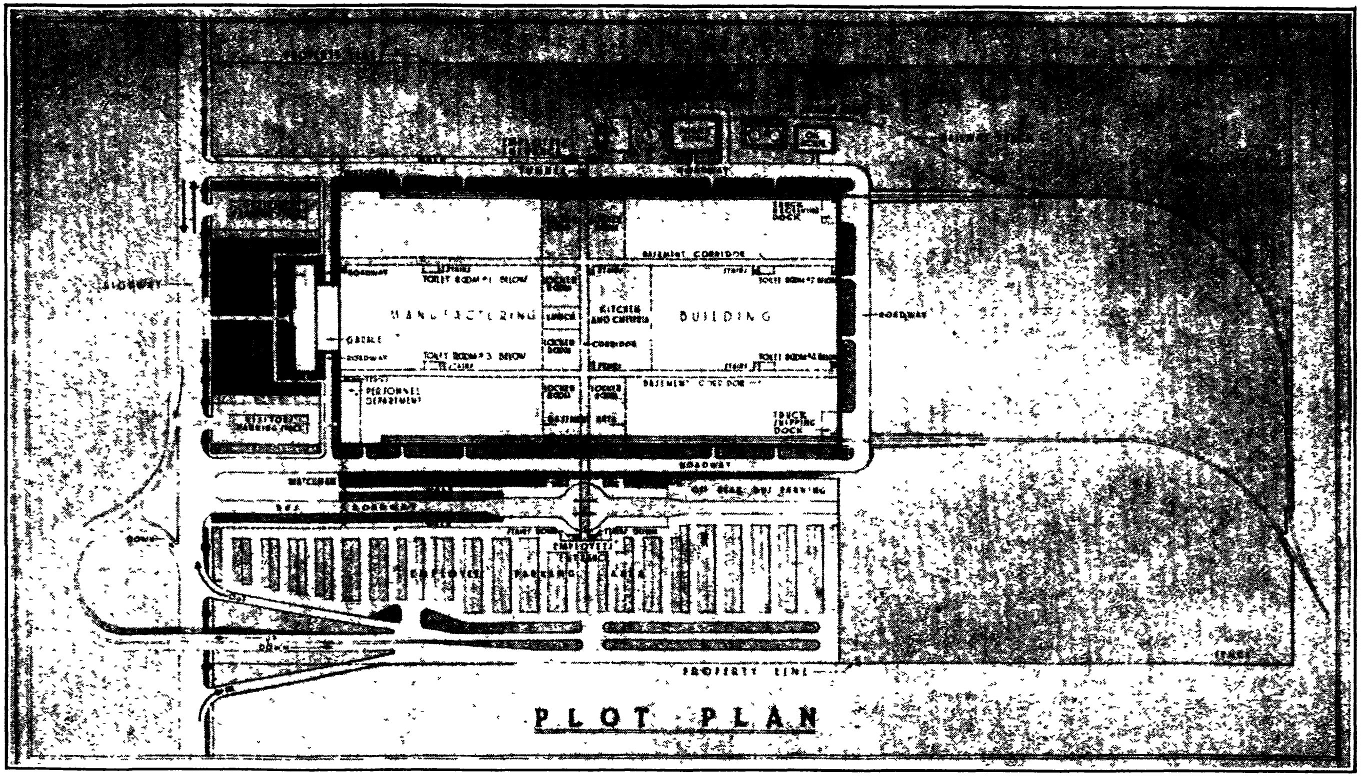


FIG. 28. *Typical plot plan* showing the complete site development for a modern manufacturing plant. By planning the over-all arrangement of the plot before building any of the structural units, much expense and delay can be avoided later as the buildings come into being. Management can thus plan its investments in plant construction and expansion with greater economy and utilization than by piecemeal planning. (*Courtesy of Albert Kahn Associated Architects and Engineers, Detroit.*)

Key Plans

In making a layout affecting more than one building or a building covering a considerable amount of ground area, a number of standard-size drawings, 24 inches × 36 inches, will be required to provide complete coverage of the plant area involved. These drawings are made in conventional scale of ¼ inch = 1 foot. In Figure 29 the plot plan of a plant consisting of 19 detached buildings is shown in two stages: (*a*) **plot plan** before being sectionalized into detail areas, and (*b*) **key plan** developed on the plot plan to identify the 96 component detail drawings necessary to cover the detail layout of the entire premises.

In order to interrelate these drawings properly and to avoid the confusion of piecing them together as in a jigsaw puzzle, the plan of the entire set is outlined on the plot plan. By using the key plan system of drawing, the entire plant, regardless of size, can be laid out on the full scale of ¼ inch = 1 foot, thereby holding down the individual drawings to standard size for filing and handling.

Floor Plans

The floor plans of the building structure, along with any required sections through the building, are traced in India ink on tracing cloth. These drawings become a permanent record of the building and are entirely apart from the drawings subsequently made of the plant layout.

Floor Blanks

Floor blanks of the building in which the layout is to be housed are drawn on 24 inch × 36 inch sheets of tracing paper, using a scale of ¼ inch = 1 foot. These floor blanks form a part of the component detail drawings identified individually by the plan numbers shown on the key plan of the premises. On these floor blanks a preliminary layout is made of the contiguous areas required for the various processing activities, storage spaces, and aisles.

General Outline of Techniques

The detail technique for making preliminary layouts on floor blanks has been reserved for Chapter IX on "Analyzing, Balancing, and Routing the Operations." In this and the next chapter, only a general outline of the techniques of plant layout engineering is discussed. The practical application of these techniques becomes the subject matter of Parts 2 and 3, which follow.

Area Diagrams

On the rough plan of the areas allocated on floor blanks, a geographic flow line of the product can be established tentatively. When the proper flow has been finally determined, the area diagram serves as the nucleus around which template layouts can be developed on the same scale of ¼ inch = 1 foot. It must be remembered that the area diagram is merely intended to serve as a guide for preparing the layout and as a quick preview of the ultimate layout.

For these reasons, the drawing detail appearing on the area diagram is con-

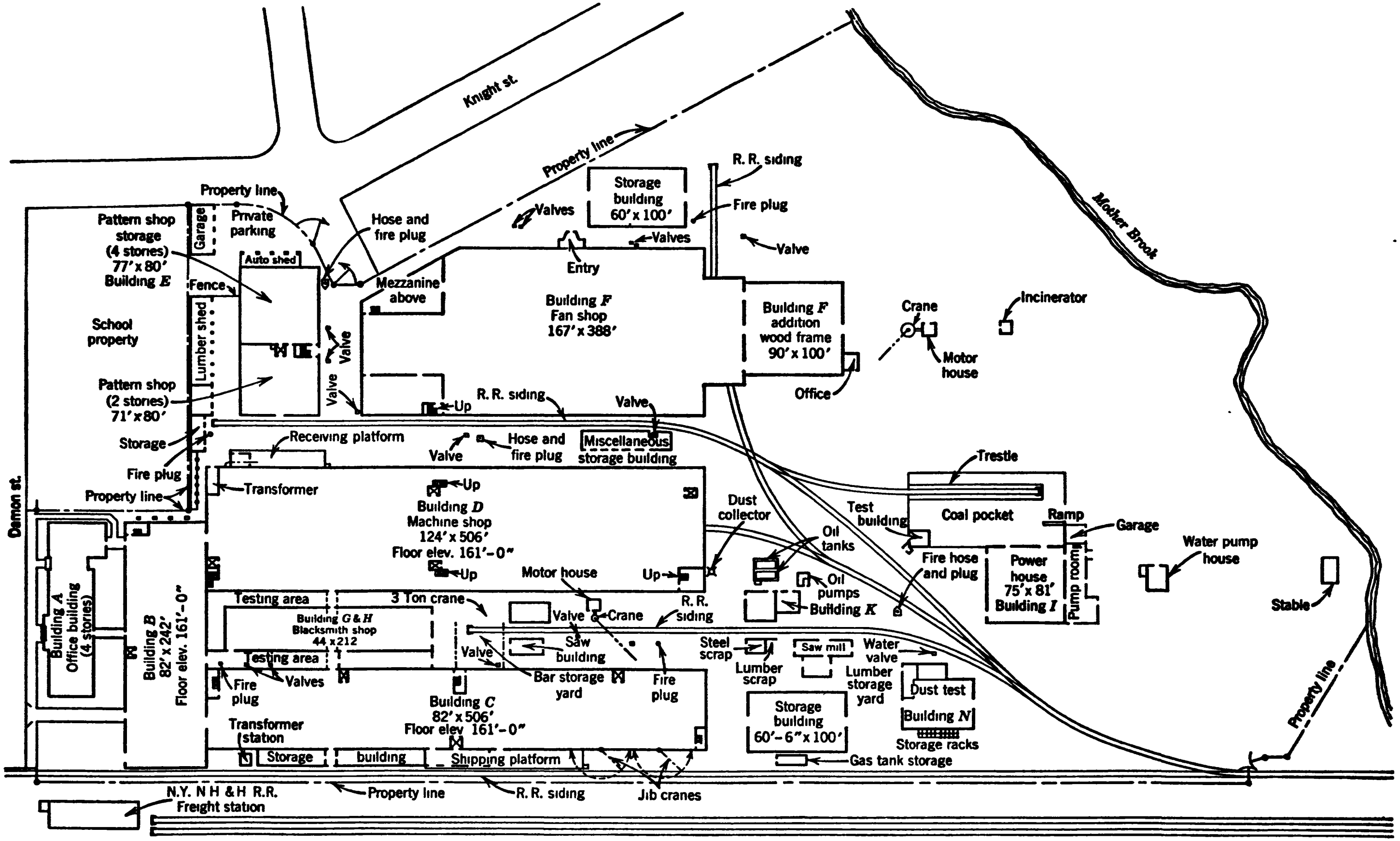


FIG. 29A. *Plot plan of a manufacturing plant* consisting of one office building, four manufacturing buildings, one blacksmith shop, one lumber shed, one garage, one power house, one saw mill, and eight storage buildings. (*Courtesy of Gaudreau, Rimbach & Associates, Pittsburgh.*)

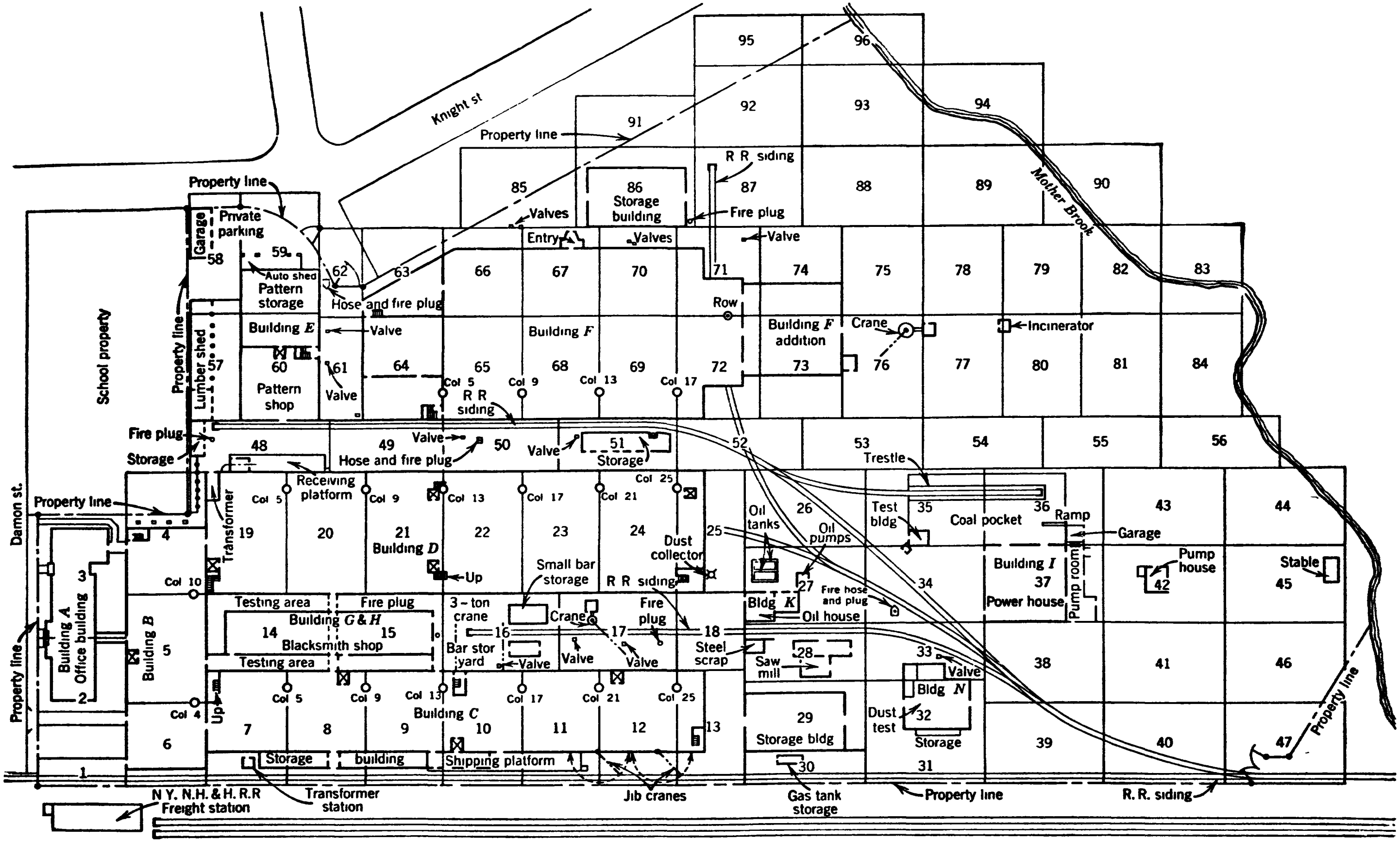


FIG. 29B. *Key plan* of the 96 separate drawings of standard size, 24 × 36 inches, on scale of ¼ inch = 1 foot, necessary to cover the detail layout of the entire ground area of the plant property in Figure 29A. (*Courtesy of Gaudreau, Rimbach & Associates, Pittsburgh.*)

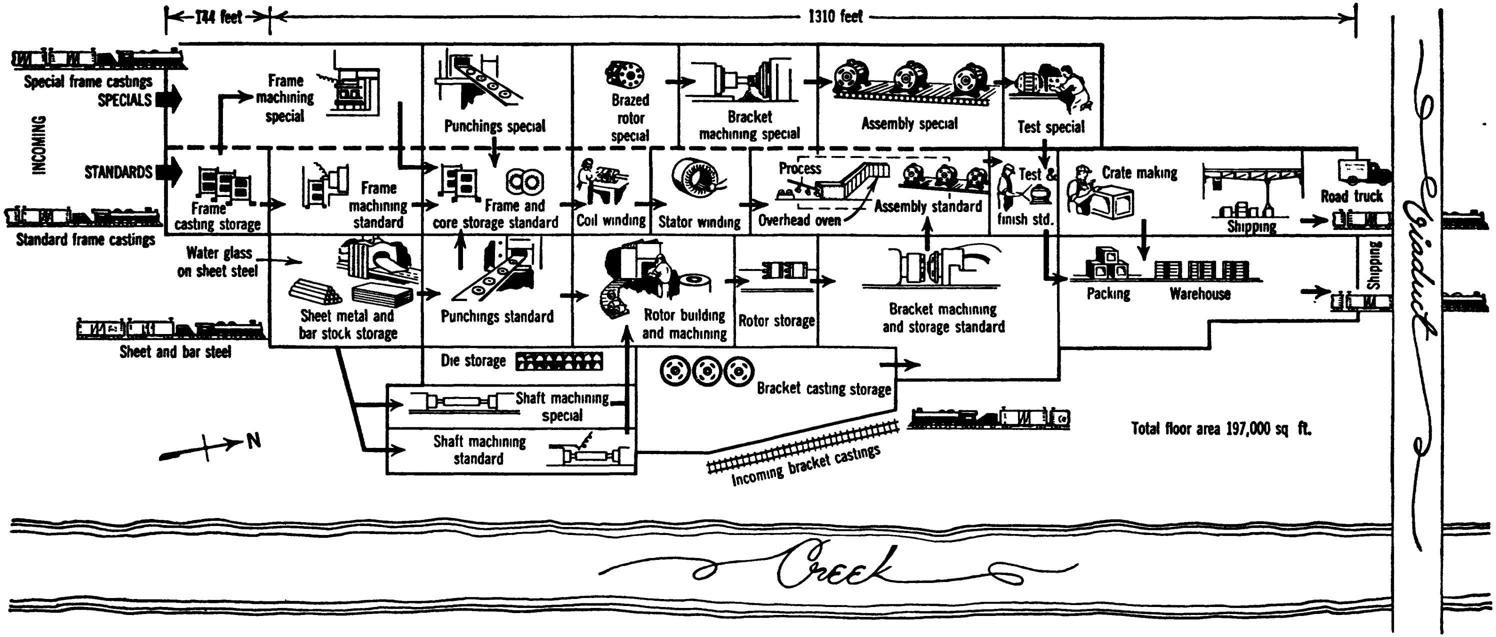


Fig. 30. *Area diagram* of an electrical-motor manufacturing plant, showing only the general arrangement of the plant and the approximate areas allotted to operations.

fined to the indication of approximate areas and locations of operations. The area diagram of an electrical-motor manufacturing plant is shown in Figure 30. It will be noted that the diagram shows only general arrangement of the plant and approximate areas allotted to operations. It does not include information regarding the type and number of machines nor does it attempt to show the arrangement of the equipment, but it does indicate the flow of material through the plant.

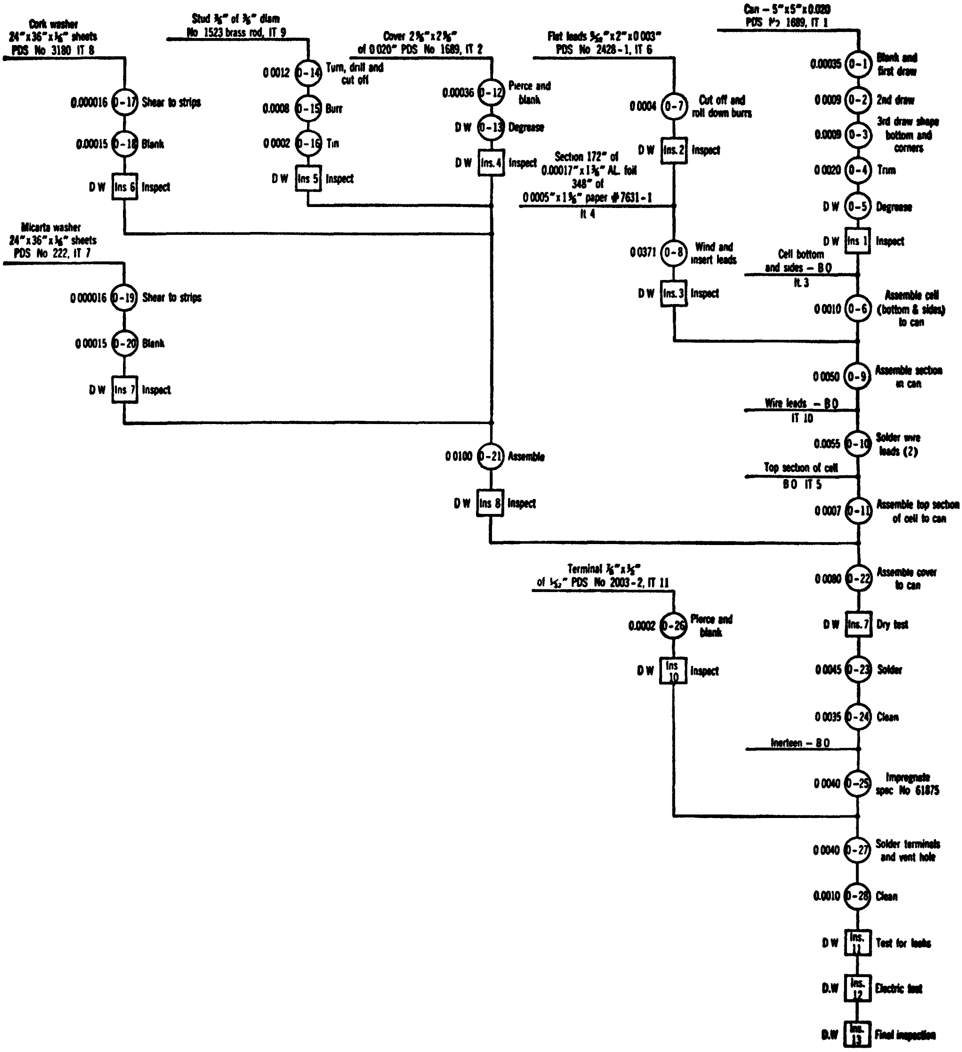

Cork washer 24"x36"x⅛" sheets PDS No 3180 IT 8
0.000016 0-17 Shear to strips
0.00015 0-18 Blank
D W Ins 6 Inspect
Micarta washer 24"x36"x⅛" sheets PDS No 222, IT 7
0 000016 0-19 Shear to strips
0 00015 0-20 Blank
D W Ins 7 Inspect
Stud ⅜" of ⅜" diam No 1523 brass rod, IT 9
0 0012 0-14 Turn, drill and cut off
0.0008 0-15 Burr
0 0002 0-16 Tin
D W Ins 5 Inspect
Cover 2⅝"x2⅝" of 0 020" PDS No 1689, IT 2
0.00036 0-12 Pierce and blank
D W 0-13 Degrease
D W Ins. 4 Inspect
0 0100 0-21 Assemble
D W Ins 8 Inspect
Flat leads 5/32"x2"x0 003" PDS No 2428-1, IT 6
0 0004 0-7 Cut off and roll down burrs
D W Ins. 2 Inspect
Section 172" of 0.00017"x1⅜" AL foil 348" of 0 0005"x1⅝" paper #7631-1 It 4
0 0371 0-8 Wind and insert leads
D W Ins. 3 Inspect
Can – 5"x5"x0.020 PDS No 1689, IT 1
0.00035 0-1 Blank and first draw
0 0009 0-2 2nd draw
0.0009 0-3 3rd draw shape bottom and corners
0 0020 0-4 Trim
D W 0-5 Degrease
D W Ins 1 Inspect
Cell bottom and sides – B O It 3
0 0010 0-6 Assemble cell (bottom & sides) to can
0 0050 0-9 Assemble section in can
Wire leads – B O IT 10
0.0055 0-10 Solder wire leads (2)
Top section of cell B O IT 5
0 0007 0-11 Assemble top section of cell to can
0 0080 0-22 Assemble cover to can
D W Ins. 7 Dry test
0 0045 0-23 Solder
0 0035 0-24 Clean
Inerteen – B O
0 0040 0-25 Impregnate spec No 61875
Terminal ⅞"x⅜" of 1/32" PDS No 2003-2, IT 11
0.0002 0-26 Pierce and blank
D W Ins 10 Inspect
0 0040 0-27 Solder terminals and vent hole
0.0010 0-28 Clean
D W Ins. 11 Test for leaks
D.W Ins. 12 Electric test
D.W Ins. 13 Final inspection

FIG. 31. *Operation process chart* for a capacitor. Each component part is identified by specification number and broken down into operations. Time values are shown for each operation. Flow lines indicate the sequence of all operations in the manufacturing cycle.

Operation Process Charts

When a variety of parts and products are manufactured which follow different paths across several floor areas, an operation process chart may be necessary for the important material items or products. In Figure 31 is shown such a chart for the manufacture of a capacitor. Each component part in this flow is identified by specification number and is broken down into operations. Time values are shown for each operation.

The flow lines on the chart indicate the sequence of all operations in the manufacturing cycle. With this type of chart as an over-all guide, area diagrams may be drawn with greater assurance of comprehensiveness and with less trials and errors.

Advantages of Charts

In using area diagrams, operation process charts, material flow charts, and template laydowns, many significant points come to light which might not otherwise be detected until after the layout has been actually installed. Examples of some of these points are:

1. Material crossovers become plainly evident.
2. Long distances between certain successive operations stand out prominently by comparison with other related distances.
3. Wasteful methods of material handling resulting from improper sequence of operations are made clearly obvious.

2. RECORDS OF EXISTING MACHINERY AND EQUIPMENT

Superfluous Records

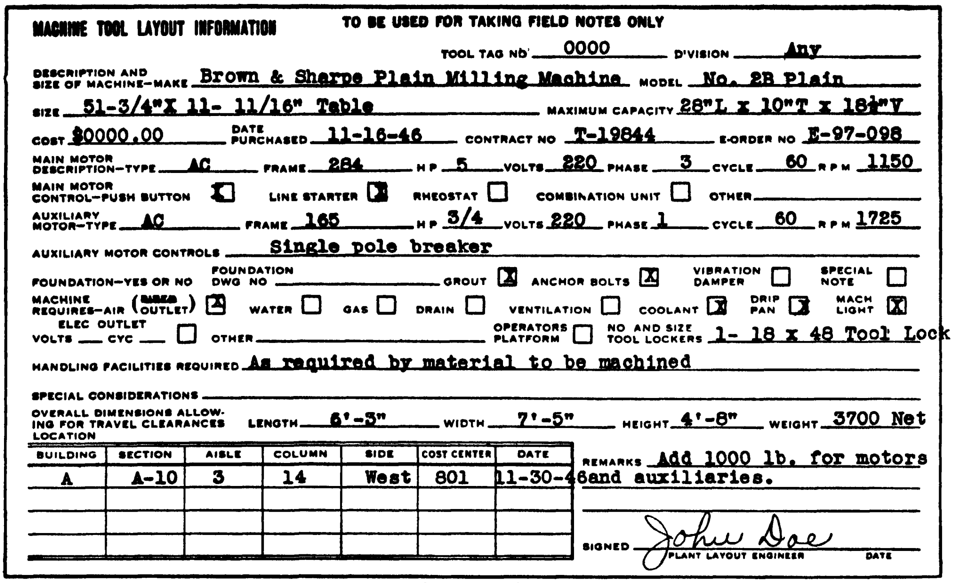
Of the many records which are sometimes kept in a plant layout office, only a specific few are of sufficiently vital necessity to justify compilation or filing. A considerable amount of operating and cost data which the plant layout engineer requires only on certain occasions is usually available in reference form in other departments. As an example, although the engineer must know all the jobs that are routed to some particular machines and the production activity of these jobs, most of this information is usually on record in the production department. It would therefore be a superfluous effort for him to duplicate these records in the plant layout office. Time-study data are likewise available in reference files maintained in other departments.

Characteristics Record of Machine Tools

It is desirable, however, to maintain in the plant layout office accurate records of characteristics of machine tools and of other processing equipment. Suitable forms for compiling this information can readily be mimeographed or photo-offset as needed. To attempt to design a standard printed form that would be suitable for all types of machinery would only lead to complications and unnecessary confusion. A more practical plan is to make up separate sets of simple forms of uniform size and character to satisfy widely different types of machines.

Machine-Tool Record Card

One of the most important records that the plant layout engineer must maintain at all times in complete and accurate state is a plant layout specification



MACHINE TOOL LAYOUT INFORMATION TO BE USED FOR TAKING FIELD NOTES ONLY

TOOL TAG NO 0000 DIVISION Any

DESCRIPTION AND SIZE OF MACHINE—MAKE Brown & Sharpe Plain Milling Machine MODEL No. 2B Plain

SIZE 51-3/4"X 11- 11/16" Table MAXIMUM CAPACITY 28"L x 10"T x 18½"V

COST $0000.00 DATE PURCHASED 11-16-46 CONTRACT NO T-19844 E-ORDER NO E-97-098

MAIN MOTOR DESCRIPTION—TYPE AC FRAME 284 H P 5 VOLTS 220 PHASE 3 CYCLE 60 R P M 1150

MAIN MOTOR CONTROL—PUSH BUTTON ☒ LINE STARTER ☒ RHEOSTAT ☐ COMBINATION UNIT ☐ OTHER

AUXILIARY MOTOR—TYPE AC FRAME 165 H P 3/4 VOLTS 220 PHASE 1 CYCLE 60 R P M 1725

AUXILIARY MOTOR CONTROLS Single pole breaker

FOUNDATION—YES OR NO FOUNDATION DWG NO GROUT ☒ ANCHOR BOLTS ☒ VIBRATION DAMPER ☐ SPECIAL NOTE ☐

MACHINE REQUIRES—AIR ([illegible] OUTLET) ☒ WATER ☐ GAS ☐ DRAIN ☐ VENTILATION ☐ COOLANT ☒ DRIP PAN ☒ MACH LIGHT ☒

ELEC OUTLET VOLTS ___ CYC ___ ☐ OTHER OPERATORS PLATFORM ☐ NO AND SIZE TOOL LOCKERS 1- 18 x 48 Tool Lock.

HANDLING FACILITIES REQUIRED As required by material to be machined

SPECIAL CONSIDERATIONS

OVERALL DIMENSIONS ALLOWING FOR TRAVEL CLEARANCES LENGTH 6'-3" WIDTH 7'-5" HEIGHT 4'-8" WEIGHT 3700 Net

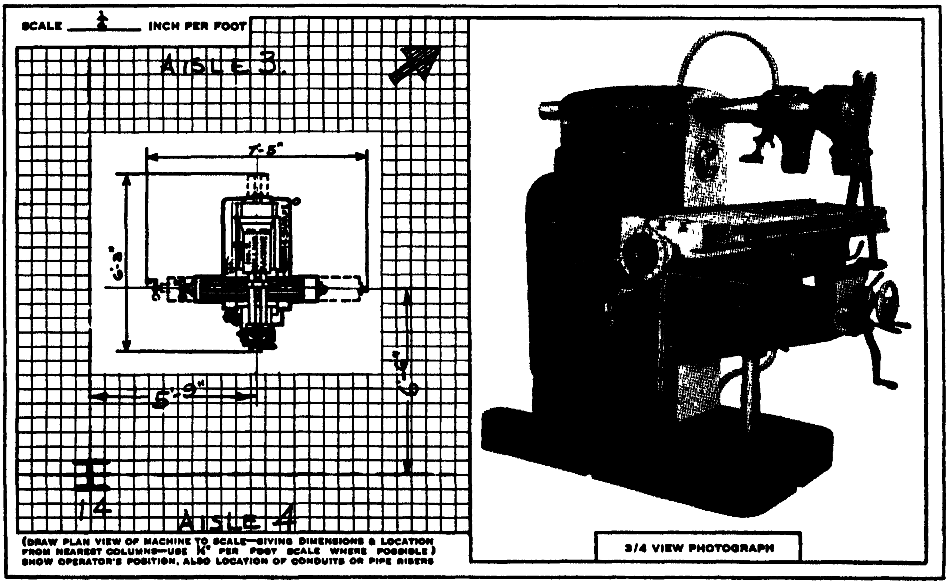
LOCATION

BUILDING	SECTION	AISLE	COLUMN	SIDE	COST CENTER	DATE
A	A-10	3	14	West	801	11-30-46

REMARKS Add 1000 lb. for motors and auxiliaries.

SIGNED John Doe
PLANT LAYOUT ENGINEER DATE

Front of card



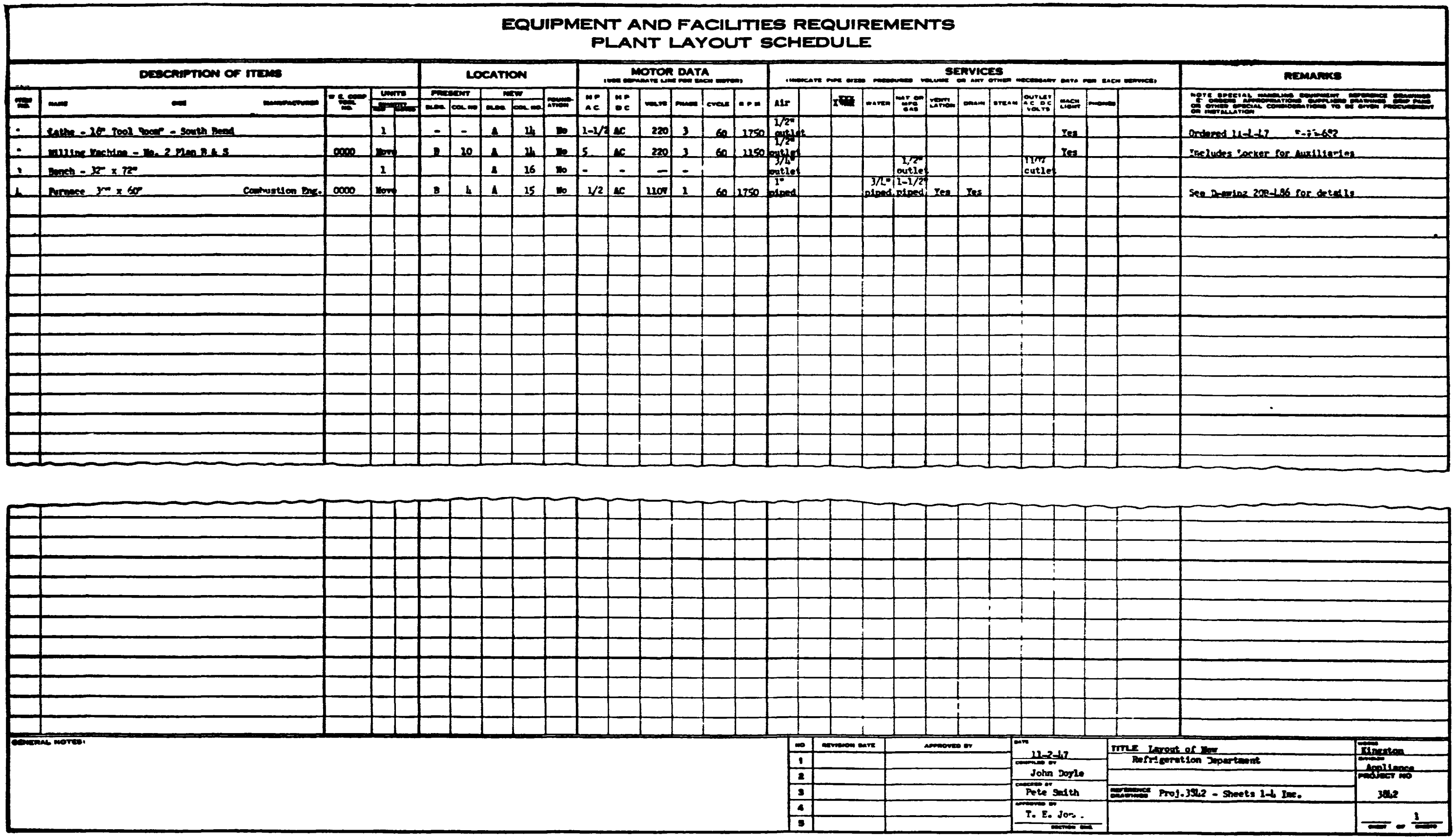
SCALE 1/4 INCH PER FOOT

(DRAW PLAN VIEW OF MACHINE TO SCALE—GIVING DIMENSIONS & LOCATION FROM NEAREST COLUMNS—USE ¼" PER FOOT SCALE WHERE POSSIBLE) SHOW OPERATOR'S POSITION. ALSO LOCATION OF CONDUITS OR PIPE RISERS

3/4 VIEW PHOTOGRAPH

Back of card

FIG. 32. *Reference card on each machine tool* obviates the necessity for making physical checks on the premises whenever the need arises for basic data on operating units. This information is summarized in Figure 33. (*Courtesy of Gaudreau, Rimbach & Associates, Pittsburgh.*)



EQUIPMENT AND FACILITIES REQUIREMENTS
PLANT LAYOUT SCHEDULE

DESCRIPTION OF ITEMS						LOCATION					MOTOR DATA (USE SEPARATE LINE FOR EACH MOTOR)						SERVICES (INDICATE PIPE SIZES PRESSURES VOLUME OR ANY OTHER NECESSARY DATA FOR EACH SERVICE)												REMARKS
ITEM NO.	NAME	SIZE	MANUFACTURER	W. E. COMP TOOL NO.	UNITS QUANTITY	PRESENT BLDG.	PRESENT COL. NO.	NEW BLDG.	NEW COL. NO.	FOUNDATION	H P A C	H P D C	VOLTS	PHASE	CYCLE	R P M	Air		[illegible]	WATER	NAT OR MFG GAS	VENTILATION	DRAIN	STEAM	OUTLET A C D C VOLTS	MACH LIGHT	PHONES		NOTE SPECIAL HANDLING EQUIPMENT REFERENCE DRAWINGS & ORDERS APPROPRIATIONS SUPPLIERS DRAWINGS GRIP PANS OR OTHER SPECIAL CONSIDERATIONS TO BE GIVEN PROCUREMENT OR INSTALLATION
1	Lathe - 16" Tool Room - South Bend				1	-	-	A	14	No	1-1/2	AC	220	3	60	1750	1/2" outlet									Yes			Ordered 11-1-47 [illegible]
2	Milling Machine - No. 2 Plan B & S			0000	Move	B	10	A	14	No	5	AC	220	3	60	1150	1/2" outlet									Yes			Includes Locker for Auxiliaries
3	Bench - 32" x 72"				1			A	16	No	-	-	—	-			3/4" outlet				1/2" outlet				110V outlet				
4	Furnace 3'' x 60"		Combustion Eng.	0000	Move	B	4	A	15	No	1/2	AC	110V	1	60	1750	1" piped			3/4" piped	1-1/2" piped	Yes	Yes						See Drawing 20R-486 for details

GENERAL NOTES:

NO	REVISION DATE	APPROVED BY
1		
2		
3		
4		
5		

DATE 11-2-47
COMPILED BY John Doyle
CHECKED BY Pete Smith
APPROVED BY T. E. Jo- .
SECTION ONE

TITLE Layout of New
Refrigeration Department
REFERENCE DRAWINGS Proj. 3942 - Sheets 1-4 Inc.

WORKS Kingston
DIVISION Appliance
PROJECT NO 3942
SHEET 1 OF SHEETS

FIG. 33. *Summary data for each unit of machinery and equipment* as taken from Figure 32. This summary sheet also serves as bill of material and simplified specification sheet on machinery and equipment. (*Courtesy of Gaudreau, Rimbach & Associates, Pittsburgh.*)

file of all machine tools involved in the particular project he happens to be working on. A convenient and readily accessible form for this purpose is the two-sided 5 × 8 inch card illustrated in Figure 32. These cards lend themselves to quick reference when filed by tool tag number or plant location. Most plants identify each piece of machinery and equipment by a property tag bearing an inventory number and affixed (through the medium of riveted plates or painted numbers) to each asset unit.

When properly filled out and filed, the machine-tool record card places at the engineer's fingertips a comprehensive summary of the plant layout data for each piece of machinery with which he is concerned. This file obviates the necessity of his making physical checks on the premises whenever he needs basic data on machine units.

Equipment and Facilities Requirements

For many years the engineering drawing alone was used as the means of conveying equipment data, such as identification, location, power requirements, and plant services affected, which are pertinent to the particular plant layout appearing on the drawing. This practice often beclouded the plant layout design itself by the necessary pell-mell insertion of numerous notations on the drawing. It also meant that everyone concerned with the machinery and equipment which figured in a layout had to refer to the drawing for needed machine data. Quite often such information was found lacking.

To conquer this shortcoming, a recapitulation form for recording pertinent data on plant equipment and facilities involved in a given plant layout has been brought into use, in recent years, as a supporting statement accompanying the layout drawing. Such a form is illustrated in Figure 33. It serves the multifold purpose of summary sheet, bill of material, and simplified specification sheet on machinery and equipment. Some of its principal advantages are listed below:

a. It keeps the plant layout drawing free of distracting and confusing notations.
b. It enables the estimators to take off readily all machine descriptions and quantities.
c. It specifically shows the order clerks what particular machinery and equipment must be ordered or moved.
d. It serves to double-check the plant layout engineer's calculations by revealing errors and omissions.
e. It permits the making of a quick checkup of the loads on power and other plant facilities.
f. It saves time and patience in hunting over a drawing for specific information on machinery and equipment. This effort must be exerted many times in the course of a project.
g. Lastly, and perhaps most importantly, it enables persons not versed in reading blueprints to secure information which they could not otherwise interpret from the plant layout drawing.

Cross-References on Drawings

It is now the general practice, wherever this recapitulation form is used, for the plant layout engineers to designate each piece of equipment by an identification number on the layout drawing and to cross-reference this item with a corresponding descriptive listing on the supporting recapitulation sheet. This sheet then accompanies the drawing in all requests for copies of the layout. This practice has resulted in saving much time and in eliminating many errors in referring to the layout.

3. FIELD NOTES ON BUILDINGS AND EQUIPMENT LOCATIONS

Checking Building Dimensions

Very seldom do architectural drawings of a plant structure represent an exact pattern of the building as actually constructed. Deviations from actual dimensions are the rule on most building plans. Irregularities of this nature arise from field adjustments made after the drawings have been completed and from tolerances allowed the building contractor for practical construction purposes. It behooves the plant layout engineer, therefore, to "field-check" thoroughly existing buildings before undertaking a re-layout. In rechecking building dimensions he frequently encounters building alterations that have been made without being reflected on the drawings.

New Drawings of Existing Buildings

It is not uncommon to find that the building drawings themselves are no longer available in some plants. In such circumstances new plans have to be prepared from field measurements of the existing structures. These drawings need not be as elaborate in architectural detail as the original set, but they should contain all the building information pertinent to a plant layout. This information consists mainly of floor plans and of an elevation plan showing a typical cross-section through each building under study. Where cranes are permanently installed in a building, these should be clearly shown on cross-sectional elevations, with the principal dimensions for each crane structure.

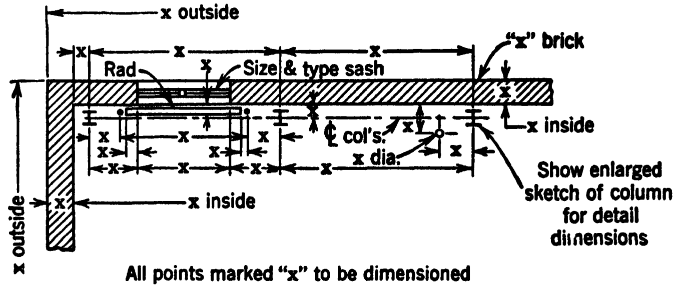
Extent of Field Notes

Rarely can it ever be felt that too many field notes have been taken for a project. This is realized when the notes are eventually plotted on drawings in the plant layout office, at which time much data are invariably found still lacking. The taking of copious field notes in the first place can save many return trips to the site for additional information later discovered to be needed.

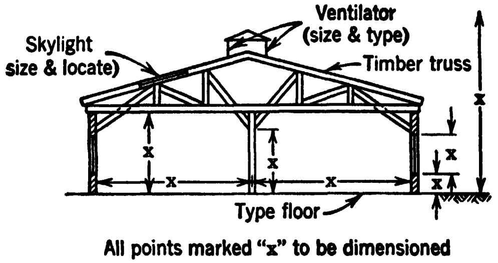
While taking field notes, it is advisable also to check the location of all machinery and equipment encountered in the building being checked for dimensions. This information should not be put on the floor plan, in as much as such entries would void the use of the plan for reproducing floor blanks needed for the layout work. When it is necessary to prepare a drawing of the existing layout, a tracing reproduction of the floor plan should be made, and the existing layout drawn up on this duplicate.

Field Sketches

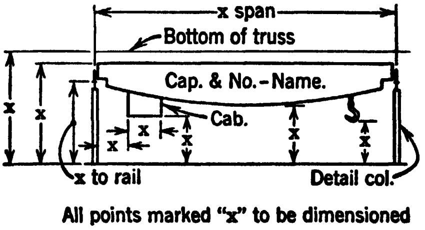
Typical of the practice followed in taking field notes for reproducing floor plans is the sketch illustrated in Figure 34*A*. The sketching of the cross-section



A. Floor plan. Typical sketch made in field notes for reproducing floor plans.



B. Building cross-section of a one-story, wooden-frame, two-aisle plant sketched in field notes.



C. Overhead traveling crane. Method of recording data for later entry on a machine record card or on the drawing of the building section.

FIG. 34. *Typical field sketches* of floor plans, building cross-sections, and overhead traveling cranes included in the field notes taken for a plant layout project.

of a building, made while taking field notes, is illustrated in Figure 34*B*. The method used for recording data on an overhead traveling crane is outlined in Figure 34*C*.

Type of Field Information

The type of information gathered in taking field notes to be used in preparing floor-plan drawings is summarized in Chapter VII, Section 3. Unless all of these points are thoroughly checked and recorded in advance, it may prove somewhat embarrassing later, after the layout has been developed, to discover that the plan calls for locating a machine tool over an existing manhole, or for erecting a storeroom bin or rack across a doorway. Moreover, downspouts, sprinkler risers, and electric switches have an uncanny way of popping up unexpectedly at just the spot found convenient for something else in the plant layout design.

4. SPOTTING MACHINERY AND EQUIPMENT ON LAYOUTS

Accuracy of Field Data

In taking field notes of dimensions and locations of machinery and equipment, many methods have been tried. Plant layout engineers are often at variance on the degree of thoroughness and extent of detail required in measuring, drawing, spotting or locating, and recording field data on machine tools and other process equipment. Years of varied experience under trying circumstances have convinced the authors that only the most accurate data and drawings will produce satisfactory results and low costs from a layout.

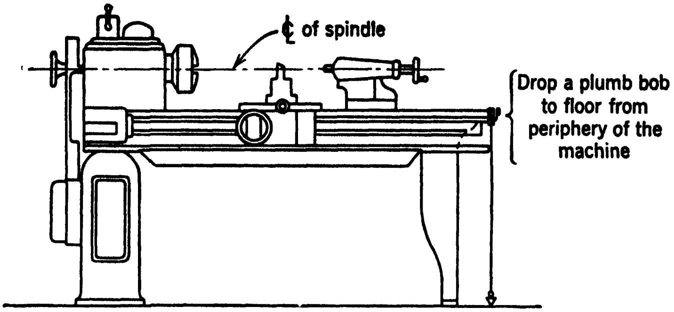
After all, a layout drawing is only a medium for communicating the thinking of a group of individuals, the plant layout engineers, to other groups of individuals, namely, the shop management, supervisors, architects, and constructors or maintenance crews. Unless this medium of transmittal is readily and clearly understood by all parties concerned, a polyglot of misunderstandings and errors invariably results from the layout drawing. When, because of a deficiency in data, the drawing gives rise to varied and erroneous interpretations while being studied by different individuals, it also usually leads to a clash of irreconcilable opinions.

Sketching Machine Templates

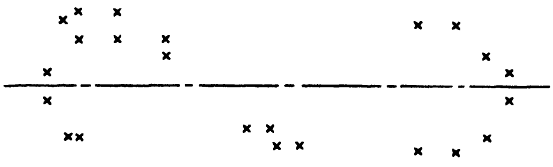
In the matter of taking field notes of machinery and equipment for the purpose of preparing templates, the template standards recommended by the American Society of Mechanical Engineers take cognizance of the importance of accuracy and thoroughness of dimension measurements. The society's Committee on Plant Layout Standards recommends that a measurement of the contour, or periphery, of the machine be made in preference to a mere "blocking out of space." Figure 35 describes in detail the two steps taken in the recommended method of drawing a sketch for a machine template while field notes are being taken for a layout;

Step 1. Project the periphery points of the machine onto the floor.
Step 2. Connect the periphery points with chalk lines on floor to give outline of machine.

When the notes are taken with the precision advocated in this method, the plant layout engineer is enabled to plan his layout with assurance. He is not

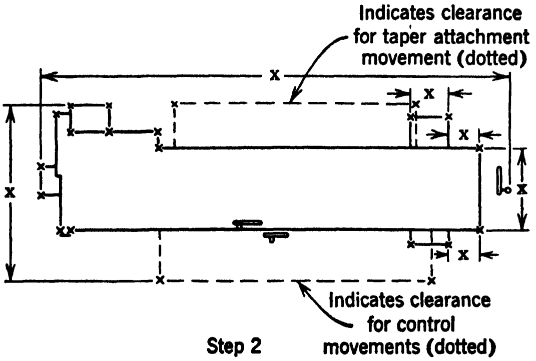


Front elevation of machine lathe, ½" = 1'



Step 1

Step 1. *Floor points.* Project the periphery points of the machine onto the floor. These points are marked with an "x" in the projection illustrated above.


Indicates clearance for taper attachment movement (dotted)
X
X
X
X
X
X
Indicates clearance for control movements (dotted)

Step 2

Step. 2. *Floor lines.* Periphery points connected with chalk lines on floor give outline of machine. Fill in the dimensions marked "x," and enter this diagram in field notes. Note the projection of the machine carriage or table travel. In recording this sketch, notate existing attachments and locations of possible future ones such as taper, grinder, miller, coolant pans, and turrets.

Fig. 35. *Floor sketch for template.* The two steps in drawing a sketch for a machine template while taking field notes.

handicapped by inaccuracies of templates, and the sketch permits him to distinguish clearly the machine proper from the areas appended for clearances and work travel. From a template drawn in this manner, he can also see readily what space is available for lockers, skids, pans, benches, stools, conveyors, and the multitude of other auxiliaries that make up the layout of a work station.

Spotting Machinery on the Layout

Of equal importance with the accuracy of the template is the accuracy used in spotting, or locating, a machine on the floor while taking field notes. Once a layout is ready for installation, the millwrights and riggers have to rely on the layout drawing as a guide for placing the machinery and equipment on the shop floor. Inasmuch as layout drawings are generally made on the small scale of ¼ inch = 1 foot, the danger of errors in placing equipment is increased 48 times in an actual foot of floor dimension.

Machinery Dimensional Lines

Owing to the multiplicity of lines that must otherwise appear on a layout drawing, it is not considered advisable to add complications to this array by including dimensional lines for each piece of machinery and equipment. Furthermore, millwrights must be permitted a certain degree of field tolerance in positioning the equipment. However, if a machine dimension must be held, as when matching several pieces of equipment during installation, only the *principal dimensions* of the machine periphery or center lines need be shown on the drawing. The millwrights will thereby find out what placement dimensions must be held, and, as a corollary, where they cannot take the liberty of field tolerances. Holding strictly to a machine dimension is, of course, the exception and not the rule.

Dimensional Reference Points

Also of utmost importance in taking field notes for a layout is the spotting of reference points for placing the templates on the drawing. These points should be so positioned and indicated on the drawing as to be identified and located readily out in the plant. No room for doubt should be left in the mind of the installer as to the meaning of a reference point on a machine or building. As an aid in avoiding such confusion, notations such as the following should appear on the drawing: "All dimensions taken from center lines of columns or from face of bricks."

Locating by Triangulation

Where center lines of machines cannot be shown, the machine structure should be indicated in such a way that a definite series of points can be determined and scaled off by the millwrights. For example, machine feet, fixed pans, main housings, chucks, spindles, and similar points can be used readily for locating purposes. Locating a machine by triangulation is illustrated in Figure 36 for a machine that can be related to a column or pilaster. Where no columns or pilasters are available for this method, the triangulation can be based on a wall corner, as illustrated in Figure 37.

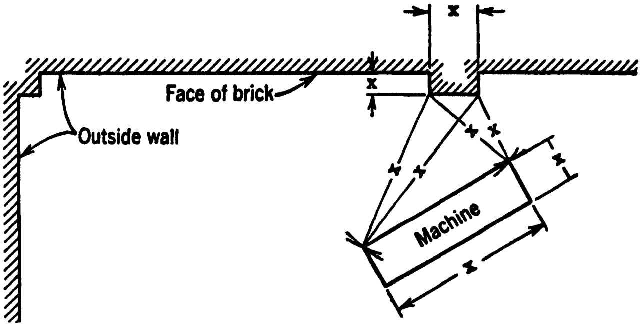


FIG. 36. *Focused on column.* Locating a machine by triangulation focused on a column or pilaster; "X" denotes dimensions required in field notes.

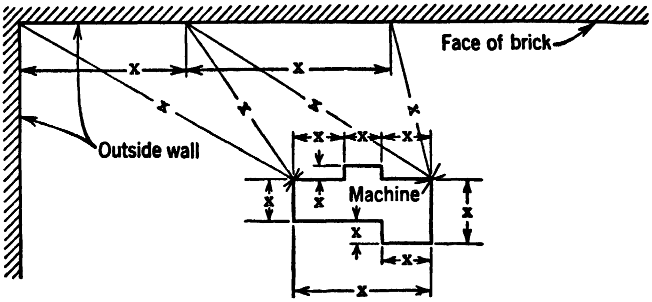


FIG. 37. *Focused on wall.* Locating a machine by triangulation where no columns or pilasters are available as focal points. "X" denotes dimensions required in field notes.

Sequence of Installing Machinery

A point for the engineer to keep in mind is that a layout installation does not always progress continuously from one end of the plant to the other without interruptions or irregular sequence along the line. The workmen install the equipment at hand as existing conditions allow. They may install one piece at one end, another piece near the other end, and then backtrack to a piece near the starting end. If the layout is not accurate, a few inches out of place here and there may mount up into a sizable difference during the final stages of the installation. Such a difference often necessitates making costly field adjustments in order to complete the installation according to plan.

CHAPTER VI

Techniques of Plant Layout Engineering

> "And first with nicest skill and art,
> Perfect and finished in every part,
> A little model the master wrought. . . ."
> From "The Building of the Ship," Longfellow.

1. PRELIMINARY TEMPLATE LAYDOWNS ON LAYOUT BOARDS

Basic Type of Layout

Much of the work of actually developing a layout of machinery and equipment is of a "cut-and-try" nature. Templates representing the machines are cut to scale and are tried in different arrangements and locations on the floor blank. In arranging these templates to form a layout of the flow of operations, the prime objective is to select the **basic type of layout** that will best suit the operations. Will the flow of production be laid out on a **product basis,** as in mass production, or will it be aligned on an **equipment basis,** as in job-lot manufacturing? The ultimate selection of the best plan, in so far as the choice between a product flow or an equipment flow is concerned, however, is not made by merely shuffling templates over a floor blank. The factors to be considered in arriving at this decision are discussed at length in Chapter VIII on "Determining the Capacities for the Design."

Template Laydowns

The information in support of the selected plan forms the basis for developing the layout. From this basic information the plant layout engineer prepares final floor plans, on which he lays out templates of machine tools, conveyors, cranes, furnaces, ovens, inspection stations, spray booths, tanks, storage bins, trucks, etc., to form departments. This function of layout engineering is commonly designated as the "template laydown."

Preparation of Templates

When making template drawings of the production facilities required in a layout, one of two general plans is followed. If the time limit for a new layout is comparatively short a blueprint is made of an existing layout, and all the machine tools and equipment items are cut out of this print for use as templates. This method saves a considerable amount of time in preparing templates, but it does not permit carrying out the standard color scheme used in regular template layout work. Nor are the templates as satisfactory to work with.

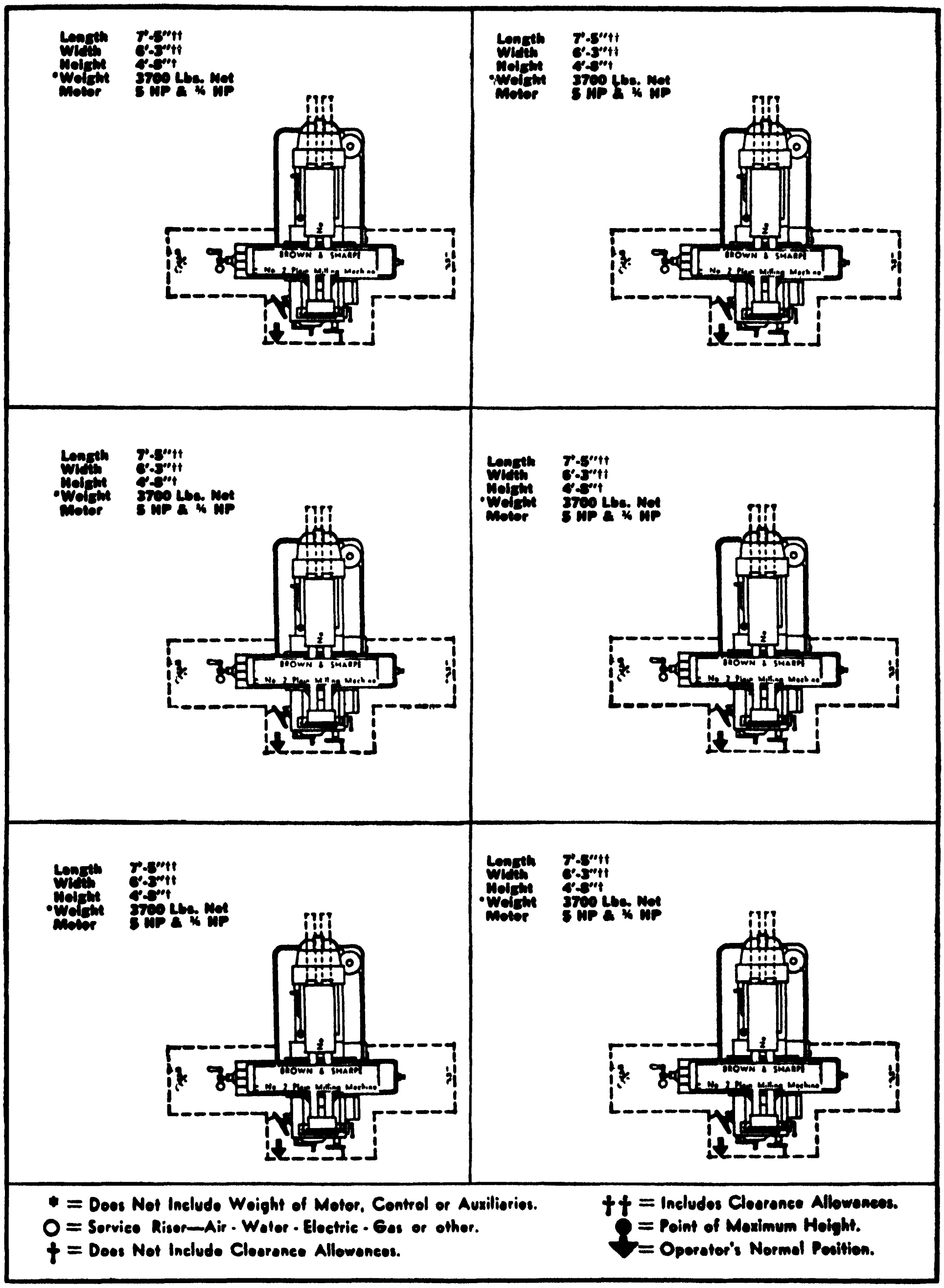


FIG. 38. *Specimen template sheet* for a specific milling machine. The sheet contains six identical templates of the same machine. With each template is shown a table listing the dimensions and weight of the machine, plus its motor power requirements.

When time permits, on the other hand, and both a more finished appearance and a permanent layout plan are desired, two-dimensional templates are made on Bristol board, or they can be purchased in printed form as illustrated in Figure 38. They are then cut out as required. The advantage of using Bristol board becomes apparent when the same templates are used over again on several layout designs of the same project or on layouts of other projects.

FIG. 39. *Mural template laydowns.* Pontiac engineers use mural boards to plan machinery and equipment layouts on template laydowns for a projected output of 500,000 cars annually. (*Courtesy of* Production Engineering and Management.)

Layout Boards

When a number of template laydowns of different departments and areas are being used in planning co-ordinated plant layouts, the laydowns are frequently made on layout boards which can be mounted on a wall for convenience of reference.

Depending upon the size of the project, layouts drawn to a scale of ¼ inch = 1 foot may run into a considerable yardage of drawings when laid end to end. To facilitate the use of large numbers of layout drawings on which two-dimensional templates are used, the drawings are placed on layout boards. These boards are then affixed to one or several walls to provide uninterrupted continuity from one layout board to another. Mural boards of template laydowns for an automobile factory are illustrated in Figure 39.

Another method for making layout boards easily accessible, particularly where wall space is not available, is shown in Figure 40. Two men can sit in the works manager's office at this plant and take a look at the entire plant without stirring from their chairs, or a fairly large group of people can be assembled for discussion of a plant move. This is made possible by a series of layout boards suspended in a frame in much the same way that an ordinary window is suspended in a spring sash. The boards can be pulled down, one at a time, and pushed up again, as needed.

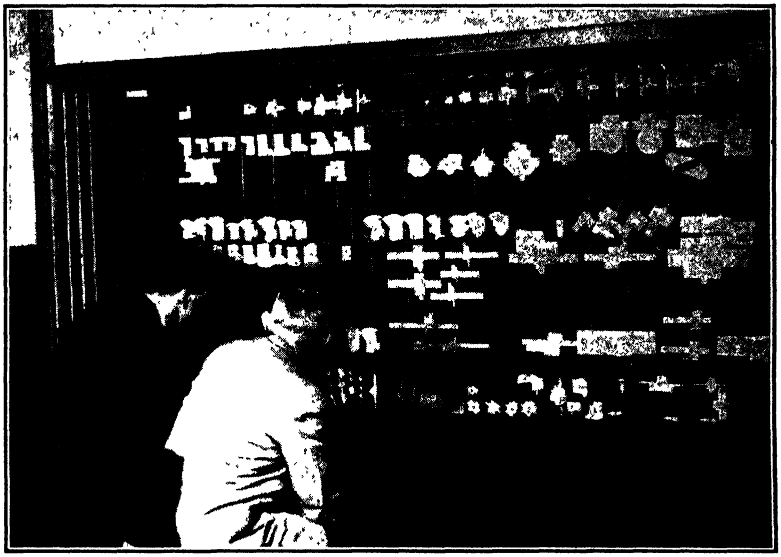


FIG. 40. *Disappearing boards* show plant layout in sections at the Bullard Company plant, Bridgeport, Conn. Six layout boards are suspended in a frame from which they can be pulled down and pushed up again, much like a window sash. The boards are 4 feet × 8 feet, and the whole frame occupies a floor space of only 2 feet × 8 feet. The layout scale used is ¼ inch = 1 foot. (*Courtesy of* Factory Management and Maintenance.)

2. TWO-DIMENSIONAL TEMPLATES FOR PLANNING LAYOUTS

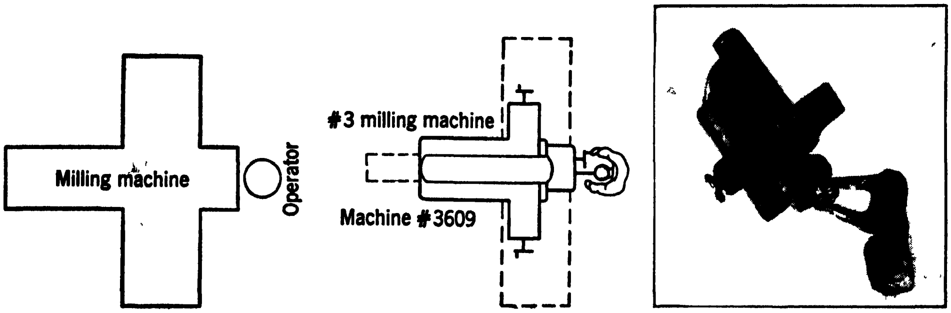
Four Planning Media

Each year American industry invests millions of dollars in new plant facilities or in plant alterations. The plans for these huge investments usually take form by application of one or more of four accepted planning media; (1) block templates, (2) two-dimensional templates, (3) three-dimensional scale models, and (4) template-model combinations.

In the early years of industrial planning, the location of equipment was a matter of spot selection as the boss walked around the available shop space. Sequence of operations and balanced machine loadings were then seldom given consideration. Plant layout usually consisted of the physical maneuvering of machines until a satisfactory arrangement was chosen on the floor itself. The principal concern was whether the space was large enough to accommodate the machine.

Block Templates

Around 1910, the general practice changed to the idea of making these arrangements on floor plans through the medium of rectangular block templates, a specimen of which is shown in Figure 41*A*. These were made of paper, cut to ¼-inch scale, to represent the floor space to be occupied by the particular machine each template represented. Since these block templates made no allowance for clearances of tables or other moving parts of the machines, service facilities were often overlooked in planning the layout. To deal with this shortcoming, the block template was frequently cut to larger dimensions to allow for clearances. Then it was found that the machine areas apparently overlapped on the layout, or that a large amount of floor space was wasted when the block templates did not overlap.



A. Block template. *B*. Two-dimensional template. *C*. Three-dimensional scale model.

FIG. 41. *Three layout media.* The same milling machine as it would appear as a block template, a two-dimensional template, and a three-dimensional scale model.

Two-Dimensional Templates

As the limitations of the block template system of layouts became more and more apparent and the need for more accurate layouts increased, the desirability of a more practical template led to the development of the two-dimensional template. For a comparison of the block and the two-dimensional templates, see Figure 41, parts *A* and *B*.

The two-dimensional template is basically a small-scale outline of the plan view of the machine, including all contours and containing principal outlines taken at a height of 7 feet above the floor. Clearance allowances, such as table travel, are dotted in on the template as required.

In reality, the two-dimensional template presents an outline drawing of the machine, showing actual floor space and clearance area requirements. It is more accurate than the block template and is conducive to a better understanding of the layout drawing. Some of these templates are now commercially available in

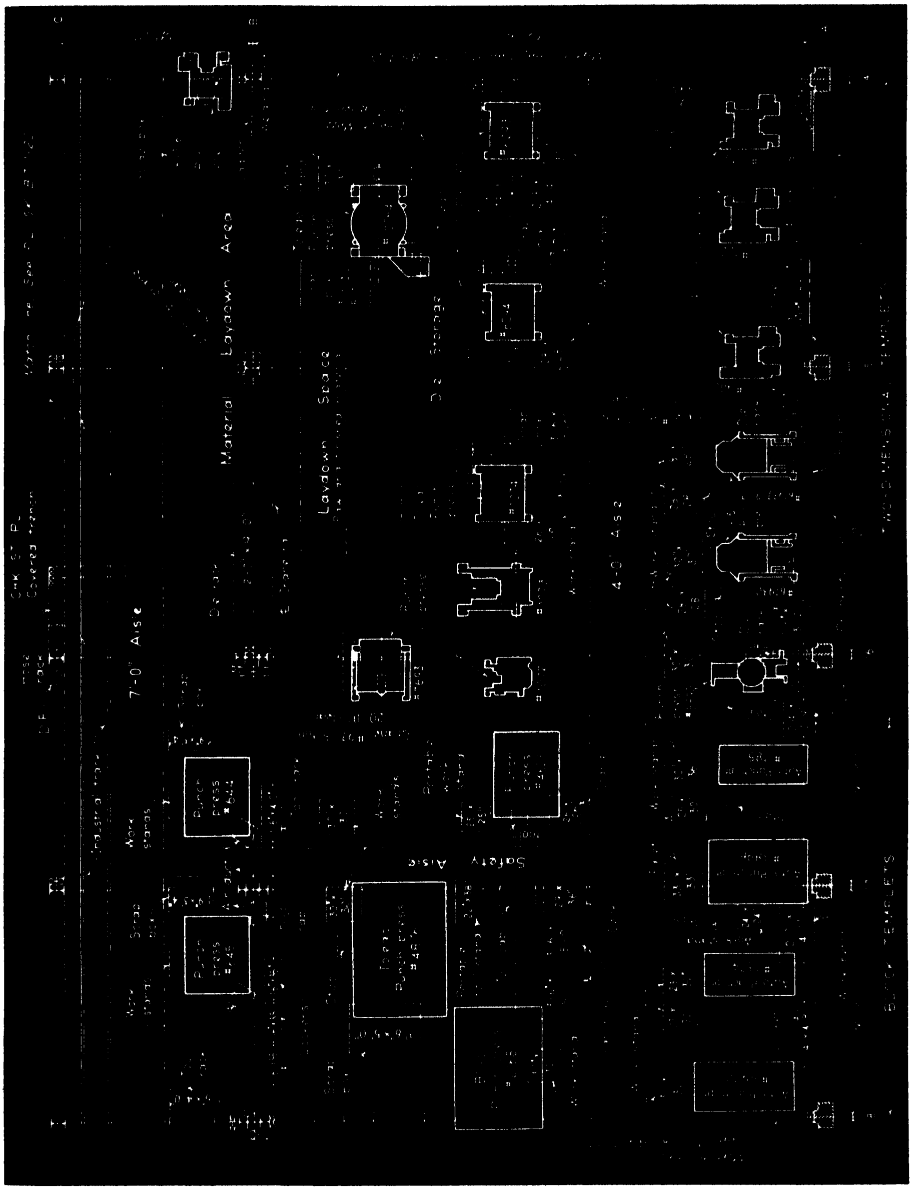


FIG. 42. *Advantages of two-dimensional templates* are shown in this layout. Note the overlap of various equipment items in the section using block templates (indicated by base line). (*Courtesy of Gaudreau, Rimbach & Associates, Pittsburgh.*)

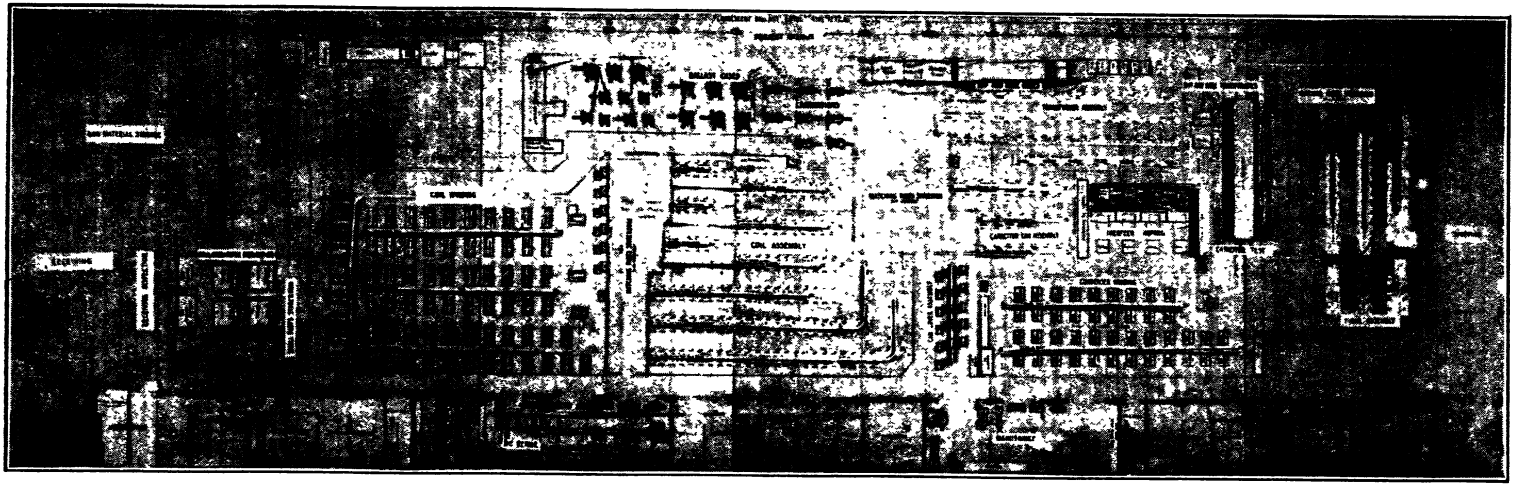


Fig. 43. *Complete two-dimensional layout* for manufacture of fluorescent ballast. Made with two-dimensional templates and ready for the preparation of final drawings, this is the most widely used type of layout. (*Courtesy of Westinghouse Electric Corporation, Pittsburgh.*)

finished form, fully dimensioned and ready for the drawing, on a printed template sheet such as the one illustrated in Figure 38.

The increasing complexity of plant arrangement has given rise to the need for the greater accuracy possessed by the two-dimensional template. Planning requirements such as unobstructed traffic movement through the aisles, adequate space for work in process, and allowance for material-handling equipment of the immobile type, such as conveyors, is now receiving due recognition in plant layouts. Furthermore, with templates representing skids, trays, storage areas, etc., the large amount of setdown space required in some industries can be readily computed. Through the medium of these templates a clear distinction is made on the layout between the floor space occupied by machinery and equipment and that which is left available for other purposes. An illustration of the advantages of two-dimensional templates over block templates is given in Figure 42.

A complete layout, made with two-dimensional templates and developed to the point where it is ready for presentation for approval, is shown in Figure 43. This type of layout planning has become very popular in recent years. In fact, it is perhaps the kind most widely used today. From this type of layout, final drawings can easily be prepared with dependable accuracy.

National Standards for Templates

As far as the design of the two-dimensional template is concerned, the amount of detail shown within the outline of the machine is a matter dictated by the requirements of the layout project. Most plant layout engineers are satisfied to show enough detail to permit easy recognition of the important parts of the machine. The center lines and easily accessible fixed points of the machine are important to the millwright for determining measurements when installing the equipment. Other information notated on the templates includes the name, type, and weight of the machines they represent. The American Society of Mechanical Engineers has sponsored a project for the development and acceptance of national standards on plant layout templates. The recommendations made for these standards are listed herewith. The establishment of these standards should aid materially in simplifying plant layout planning as well as in eliminating many of the present sources of errors and misunderstanding arising from conflicts in the technique of using templates on plant layouts.

ASME STANDARD PLANT LAYOUT TEMPLATES AND MODELS

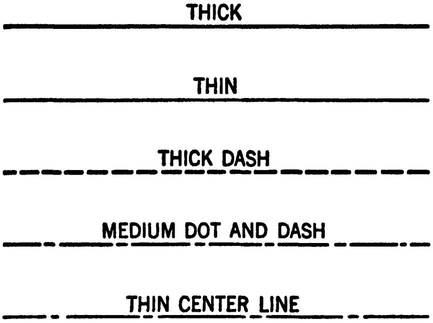
Introduction. This standard is intended to cover the engineering detail to be incorporated in design and production of two-dimension templates and three-dimension models for representation of equipment used in the planning and layout of industrial, commercial, and similar plant facilities. Nothing in this standard is intended to conflict with any existing or established standards, or any accepted drafting practice, and is compatible with general practices now used.

Scope. This standard covers two-dimension, one-plane templates, and three-dimension equipment models, generally used for determining general arrangement of related equipment and structures.

Part I. Templates

1. Scale. All templates shall be drawn to a scale of ¼ in. equal to 12 in. of full scale or ¼ in. equal to 1 ft, U. S. measure. All dimensions shall be shown in feet and inches.

2. General Outline. Outline of the equipment in heavy line indicating the contour as it would be described on the floor if a plumb line held at a height of 7 ft above the floor were to be followed around the periphery of the equipment and touching every extremity point when making a complete circle of the equipment, except for wheels or handles, etc., which should be indicated as a detail. (See recommended lines below.)



THICK	Fixed outline of machine tool or equipment from floor level to 7′-0″ elevation above floor level
THIN	Detail parts and substructures
THICK DASH	Clearances for moving parts of machine tools or equipment
MEDIUM DOT AND DASH	Overhead or underground elements—foundations, pits, service clearances and other elements important to the template
THIN CENTER LINE	Center lines

3. Detail. Particularly on machine tools and mechanical equipment, center lines, loading points, control points, and operating points should be indicated using a lighter line than used for the machine outline. Enough detail of plan view features should be included within the outline of the template to make it clearly distinguishable and important points easily located.

4. Clearances. All clearance lines including movable parts, service access points and clearances required for feeding or operating, should be shown in broken dash lines. Space allowed for material storage and other purposes, not required specifically for the equipment installation, service or operation *should not* be included in the template.

5. Interferences. Parts or structures above the 7 ft height, or foundations or substructures below floor level, should also be indicated. These are usually of importance to the installation or operation of the machine or might serve as obstructions. It is usually required that they be shown on final drawings. These features should be drawn in light broken lines of a different character than clearance lines.

6. Data. On templates of equipment with top surface of varying height, the point of maximum height should be indicated on the templates with a suitable symbol. The overall length, width, and height, including machine travel clearances, but not including operating or feeding clearances, also weight and horsepower, should be specified on or adjacent to the template.

7. Identification. Space should be provided on the template to specify the name, style or model, size, and user's identifying number.

8. Miscellaneous. Indication of controls, service facilities, connection points, or conduit or pipe risers, operator's position, and any other special feature should also be included on the template or included in the data. The operator's position should be indicated by a heavy arrow (↓).

9. Printing. Templates should be printed on both white and colored stock of at least 110 lb weight, index bristol or equivalent. Various classes of equipment should be printed with black ink on stock of distinctive colors to permit ease of perception. Colors for colored stock templates are:

CLASS	COLOR
Machine tools, mechanical equipment, and similar devices	Salmon
Office equipment; stationary equipment, such as benches, bins, racks, lockers; service facilities, such as lavatories, toilets, etc.	Green
Material-handling equipment	Yellow
Space occupying portable auxiliaries used for material handling or temporary storage (such as skids, tote pans, pallets, trays, etc.)	Red

PART II. MODELS

10. Scale. All models shall be made to a scale of ¼ in. equal to 12 in. of full scale or ¼ in. equal to 1 ft, U. S. measure.

11. Detail. The amount of detail to be designed into the model shall be governed by its utilitarian value. Sufficient detail as to form, shape, contours, special design features, etc., should appear to make the model readily distinguishable as representative of the actual equipment. Unless no other means of detailing are possible, no moving parts should be designed into the model. All points of control should be clearly indicated. Hazard areas should be clearly indicated. All normally moving parts should be shown in mid-point or neutral positions. Control or operating points should be in normal or neutral positions. Models should in no way be distorted from actual appearance of the equipment represented.

12. Finishes. All models prepared for distribution commercially shall be finished with materials and in colors, duplicating as nearly as practical the finishes most frequently used in the object represented. Where there is a multiplicity of finishes normally used, models can be finished correspondingly. (Example, office furniture.)

In the case of machine tools, the manufacturer's standard should be followed in so far as practical or the recommendations of the Machine Tool Builders Association.

In the case of equipment having machined surfaces, these can be indicated with aluminum paint.

Control points can be indicated by application of light-buff paint as recommended for two-tone painting of equipment for better visibility and safety.

Where models are made and/or used exclusively by one company or client, their particular practice should be followed.

13. Allowances and Clearances. No dimensions should be exaggerated in the model to allow for clearances. With each three-dimensional model shall be provided a two-dimensional template showing all clearances required under extreme operating and service conditions of the machine proper. The template shall not show requirements of operator, materials, auxiliaries not fixed to the machine, or other conditions not required in the basic machine or equipment. The template shall be imprinted with all pertinent information required by the planning engineer and shall include or provide for at least the following information: Name or description, model number, type, size, owner's identification number, maximum clearance dimensions (length, width, height), center lines and weight. Where the template is too small practically to contain all the foregoing information, the name and model number only shall be provided. Where possible, data on overhead or underground requirements should be shown.

NOTE: See Part I [of the Standard] covering plant layout templates.

14. Materials and Construction. Models shall be made of any suitable material that will permit normal handling without distortion or damage to finish. It should resist fracture or spalling when coming in contact with other models or materials in general. It should resist breakage or distortion when dropped from a height of 2 ft onto a solid hard surface. Models should have sufficient weight and balance to remain in position when normally arranged and subject to slight jarring or vibrations. The base of the model should be so designed as to

permit it to remain in a position once placed or to be fitted with pins to permit fastening in position. These are to be optional with the user.

Where pins are used the template should be pierced with holes to allow the model to become accurately located in relation to the template and the entire assembly held in position on board by the pins fitted to the model base.

15. Identification. Models shall bear the name and/or trademark of the equipment represented. The model number or size description should also be included if possible. Abbreviations or initials should be used where practical. The markings should be made in the most suitable place rather than attempting to place them in the same position as on the actual equipment.

16. General. Models shall be so designed and constructed to permit them to be used in conjunction with standard templates designed to represent the same identical items of equipment.

Discussions

17. Scale. This scale has been standard for years among architects and engineers engaged in industrial-plant design, and the majority of existing records are at this scale. Experience has proved this scale to be sufficiently small to permit the layout of relatively large projects, yet adequately large to permit the study and arrangement without the danger of inaccuracy caused by too small a scale. For exceptionally large projects, the panel system of drawing now used by a number of companies provides the benefit of using this standard scale, without the need of resorting to unusually large drawings of inordinate dimensions. The models should be made to the same scale as drawings so that models can be directly superimposed on floor-plan drawings for the purpose of study and presentation.

18. Detail. Distortion of models will lead to optical illusions and probable errors in study of arrangements. Clearances and other features necessary to consider will be discussed under Par. 20. Since models will be used to represent layouts to nontechnical personnel, as well as for engineering study, the final result should approach as nearly as possible a representation of the actual average conditions to be found in the completed project.

19. Finishes. True representation can be best achieved by an accurate duplication of conditions. Unless a standard of finish is followed as noted, models prepared or secured through several sources will not harmonize.

20. Allowances and Clearances. Three-dimensional layouts have their primary value in engineering design study and presentation of the layout to nontechnical persons. They do not in themselves afford permanent records, nor can certain conditions of engineering significance be presented with models alone. Therefore the two-dimensional template used in conjunction with the three-dimensional model provides the greatest benefit of both means of plant-layout approach. When arrangement of a unit is determined, the placing of the template under the model provides the missing features and when fastened in position, it provides a permanent record of the selected arrangement.

It can be then reproduced for permanency by photography, or engineering drawing, and provides a means of transmitting the information to others. The models can then be re-used as desired. Templates can be furnished in any quantities for use with one model.

Properly designed templates provide precalculated data vital to the engineer and which cannot be contained in a model.

One engineering firm advanced this plan of approach and is developing the details. If meritorious, the plan may be extended commercially.

21. Materials and Construction. Models must be reasonably durable to be of value. Tendency to slight this consideration will have a definite reaction toward their use.

22. Identification. Markings, especially size or type description, are essential to prevent errors in preparing layouts. The probability of interest on the part of equipment suppliers in furnishing models of their equipment also justifies correct identification for whatever advertising value it possesses.

The six points which have been covered appear to be the basis on which standards for plant layout models can be formulated. It is expected that further contributions will be made by equipment manufacturers, consulting engineers, and model builders, as well as those with user co-operation interests.

3. SCALE MODELS FOR LAYOUT PROJECTS IN MINIATURE

Limitations of Templates

The marked improvement brought about in plant layout practice through the introduction of the two-dimensional template is attested by its widely accepted use today. Nevertheless, this template is still only an unrealistic medium of illustration used in drafting-board technique. A wide gap yet exists between what the template purports to represent on an engineering drawing and the image it actually brings up in the minds of top executives. This is particularly true of those executives who have not had the opportunity or inclination to acquire a thorough familiarity in reading blueprints. In mechanical drawing practice, the draftsman's delineation inevitably fails to convey a realistic image of a machine or piece of equipment. The drawing can only show a flat outline of the machine or equipment. The massiveness, depth, height, and clearances of the machine are perforce left to the imagination of the reader of the drawing.

Degrees of Visualization

Although one man's eyes normally can view an object in real life as readily as another man's eyes, barring differences in effectiveness of eyesight, the "mind's eye" varies considerably in degree of imagination among different individuals. Architects and commercial artists, in recognition of this inequality among their clients and readers, have resorted to perspective drawings and diagrams in an attempt to convey a more realistic grasp of their designs. A plant layout pictured with two-dimensional templates varies in interpretation as does the one-plane presentation still sometimes used by architects and commercial artists.

Varying Versions of Drawing Technique

Another handicap confronting the reader of engineering drawings is the difference in technique employed in different fields of engineering in preparing these drawings. It is not unusual for the engineers in one particular branch of engineering to find themselves hard put to decipher the drawings prepared by engineers in another branch. Is it any wonder that busy executives frequently have little patience in struggling with drawing technique that engineers themselves have difficulty in understanding?

Advent of Scale Models

To overcome these limitations, plant layout engineers began developing miniature scale models of machinery and equipment about the time of the outbreak of

World War II. The early models were hand-carved out of wood, to the scale of ¼ inch = 1 foot, and were both crude in design and expensive to produce.

It was not long, however, before precision-scaled models cast in metal were introduced. A comparison of these two types of models for the same milling machine is made in Figure 44. The lower cost, greater accuracy, and stronger eye appeal of the cast-metal model promptly gained favor for it over the wooden model. Cast-metal models of most types of standard machinery and equipment, plus many types of special machinery, are now available on the market at advertised prices. The authors pioneered in the development of these scale models and standard templates.

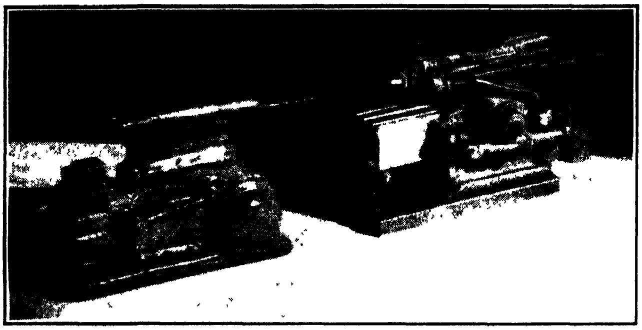


FIG. 44. *Evolution of scale models.* Hand-carved wooden model, at left, compared with cast-metal model of the same machine, at right.

With the introduction of these scale models, plant layouts at once assumed depth and reality nonexistent in the flat-template medium. Now, with scale models, it is possible to move tiny figures of men and machines around in miniature factories. Metal models, molded for permanency and accuracy, form a "bank" from which plant layout engineers may draw to plan their tiny industrial domains. In these banks is a supply of each type of machine and equipment used in the factory being laid out. The miniature machines and models of material-handling equipment are placed in the miniature plant and moved about like pawns on a chessboard. Preconstruction in miniature and rearrangement of existing plants are both equally served by these miniature models. In fact, no layout problem is too large or too small to be planned visually with scale models.

National Standards for Models

Sufficient detail is reproduced in the cast-metal model to make the represented machine easily recognizable as to type, size, and manufacturer. These models are usually scaled ¼ inch to the foot and are designed in accordance with the national standards, shown in the table on pages 97–101, recommended by the American Society of Mechanical Engineers.

Template-Model Combinations

Models alone are not sufficient for the plant layout engineer to design a proper layout. Since the layout must be converted eventually into an engineering drawing for record purposes, the model arrangement by itself leaves much detail work for the draftsman to do. A combination of two-dimensional templates and three-dimensional scale models, as shown in Figure 45, consolidates the best features of both media. Under this combination plan, the layout arrangement

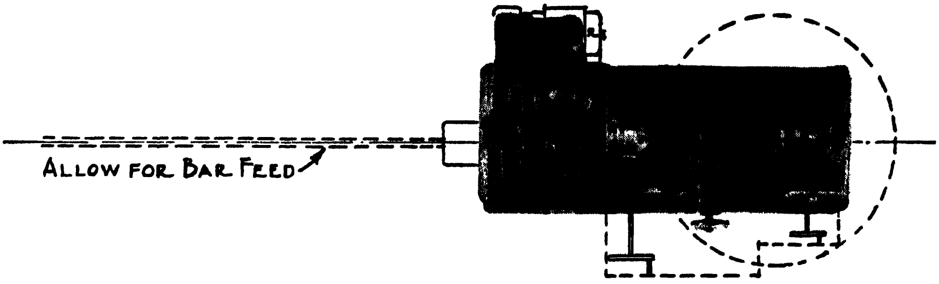


FIG. 45. *Template-model combination.* Use of a two-dimensional template in combination with a three-dimensional model gives a full visualization of a turret lathe and all its clearances.

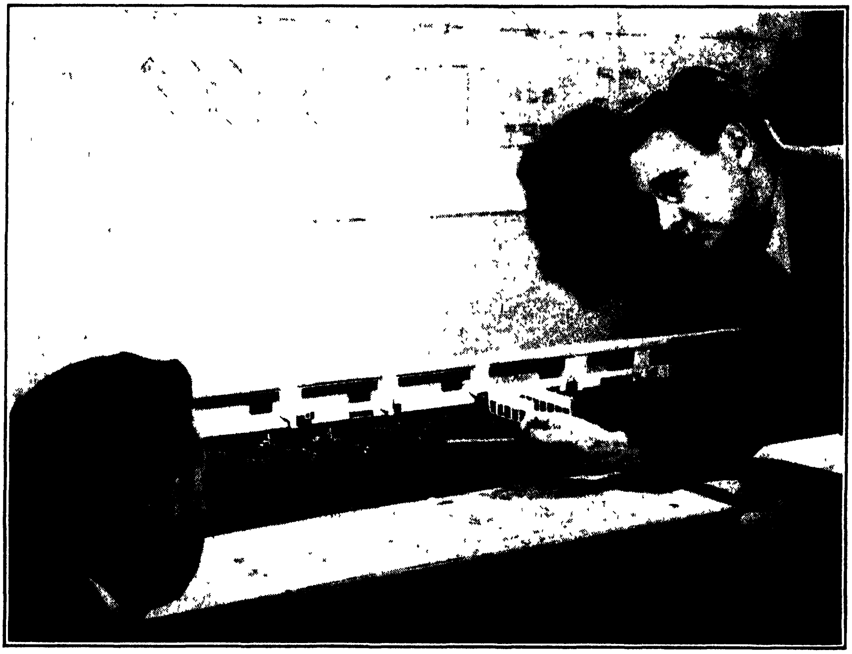


FIG. 46. *Three methods of presenting the same layout.* On the table in the foreground is a template laydown which is duplicated by scale models arranged on the shelf behind. The same layout appears also in drawing form on the wall. (*Courtesy of Westinghouse Electric Corporation, Pittsburgh.*)

is made with the models. To the base of these models are attached, with double-faced adhesive tape, the corresponding templates showing all clearances. When the desired layout arrangement has been achieved, the templates are affixed permanently on the layout, by means of staples or adhesive tape, and the models are removed for reuse on other projects.

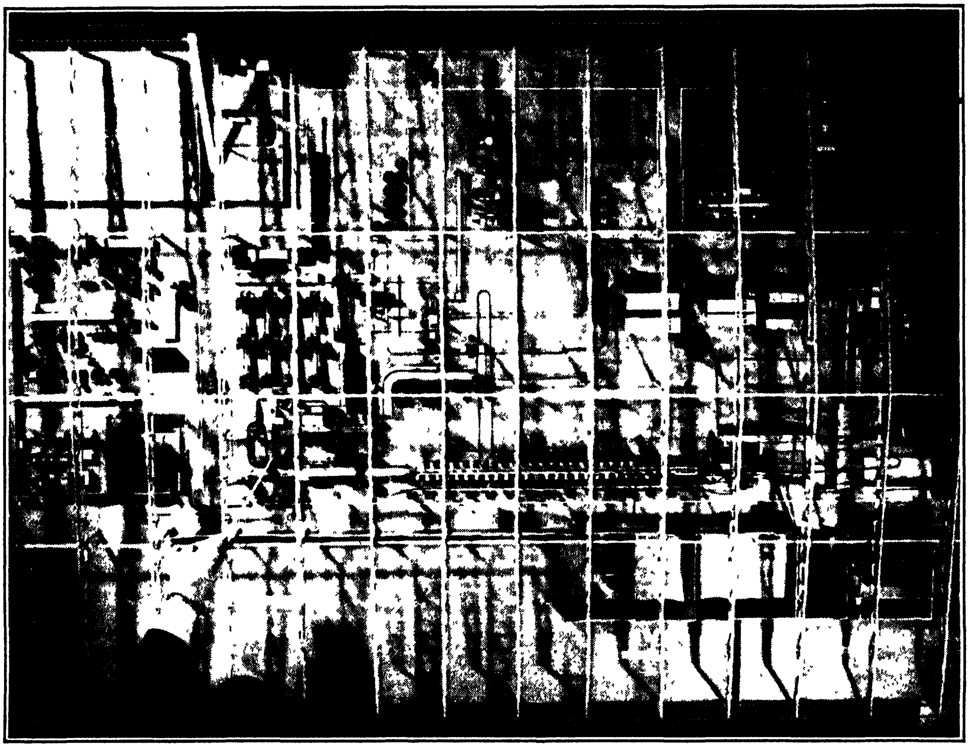


FIG. 47. *A complete plant layout made with three-dimensional scale models,* ¼ inch = 1 foot Checkerboard effect is from the roof trusses, as the view is taken looking down vertically through the open roof. Note the shadows created by the models, the alignment of the machinery and equipment, conveyor structures, aisles, and open floor spaces. (*Courtesy of Gaudreau, Rimbach & Associates, Pittsburgh.*)

The four planning media discussed in this chapter as being of general acceptance consist, as we have seen, of: (1) block templates; (2) two-dimensional templates; (3) three-dimensional templates; and (4) template-model combinations. Block templates have been dismissed as having been largely replaced by the more dependable medium of two-dimensional templates. The template-model combination, on the other hand, represents a combined application of the second and third media. A comparison of the two-dimensional templates and the scale models is made in Figure 46, together with a layout drawing of the same project. The template laydown is on the table; the corresponding scale model appears on the shelf in the background; and the resulting drawing of this layout is seen spread out on the wall, just above the shelf.

Complete Layout with Models

The marked effectiveness of scale models in developing plant layouts is illustrated in Figure 47. Here, a complete layout is viewed looking down through the roof trusses. The layout shows railroad sidings, incoming materials, machinery, equipment, and the building structure.

Co-ordinate paper instead of architectural floor plan was used for the base. This substitution is optional. Co-ordinate paper facilitates the calculation of locations of equipment by means of the scaled, printed squares. Architectural floor plans, on the other hand, are more realistic in that they contain engineering information and thus save time in ultimately drafting the final plan.

Developing a Layout with Models

The four stages recommended in developing a plant layout by means of scale models and two-dimensional templates are illustrated in Figure 48. These stages are:

1. **Working tools.** Blank floor plan, template sheets, and scale models are obtained for the layout.
2. **Realistic view.** Models are placed on the floor plan to set up a preliminary arrangement of machinery, equipment, furniture, workers, etc. At this stage the layout can be viewed in three dimensions, and suggestions invited from interested parties.
3. **Template laydown.** After the models have been placed in tentative positions, corresponding templates are slipped under the scale models to show the necessary clearances and other pertinent engineering data, such as dimensions.
4. **Completed plan.** When final arrangement has been decided upon, the models are removed, and the templates are cemented on the floor plan ready to be photographed or traced on the final layout drawing.

4. PROCEDURES FOR PREPARING A PLANT LAYOUT

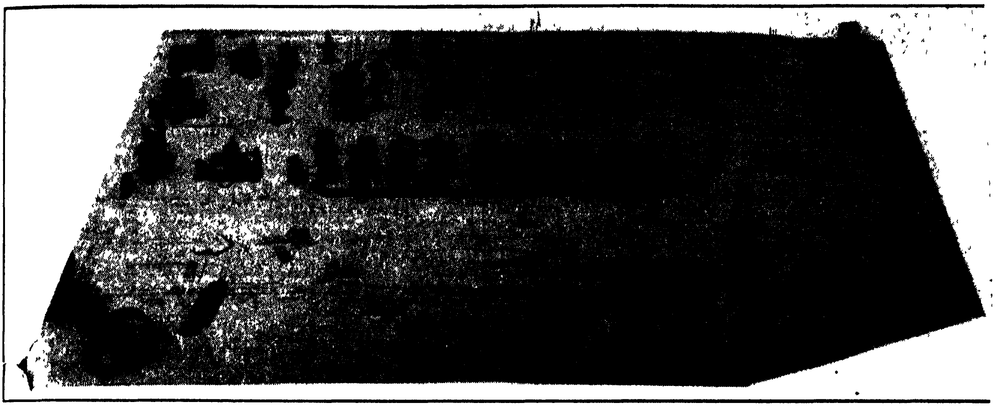
Output Capacity

In making a layout with templates, models, or a combination of both media, it is necessary to provide sufficient output capacity at each work station to take care of the production traffic, without interrupting the flow of production with bottlenecks in some stations or building up overcapacity in others. The synchronization of work-station capacities is perhaps the most important function of plant layout work at this stage. The importance of this provision cannot be overemphasized.

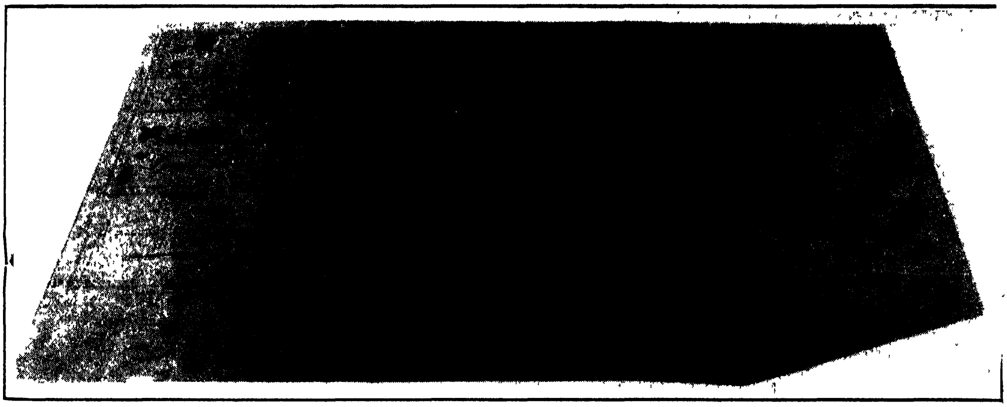
The proper type and quantity of machines, cranes, conveyors, elevators, workbenches, etc., called for in the production estimates, are all shown in the layout. These production estimates also form the basis for determining the amount of bin and storage capacities to provide for in dispatch stations and storerooms. Arrangements are made with the production department at this point to set up

tage 1. Working tools. Blank floor plan, template sheets, and scale models designed to ASME-recommended standards are obtained for the layout.

Stage 2. Realistic view. **Models are placed on the floor plan to set up a preliminary arrangement of machinery, equipment, furniture, workers, etc. At this stage, the layout can be viewed in three dimensions, and suggestions invited from anyone concerned.**



Stage 3 Template laydown. After the models have been placed in tentative positions, correspondin templates are slipped under the models to show the necessary clearances and other pertinent data, suc as dimensions.



Stage 4. Completed plan. When the final arrangement has been decided upon, the models are removed, and the templates are cemented on the floor plan ready to be photographed or traced on the final layout drawing.

FIG. 48. *Four stages in developing a plant layout* by means of models and templates. (*Courtesy of Gaudreau, Rimbach & Associates, Pittsburgh.*)

an adequate production-control system which will fit the layout. This system should also make possible the realization of the proper functioning of the layout when production actually flows through it.

Flow of Production

The templates or models are placed in operation sequence for a layout on a **product** basis, or in groups of like machines for a layout on an **equipment** basis, depending on the type of layout selected.

The flow of production is traced through strategically located dispatch stations, machining areas, assembly areas, stock storage, and shipping platforms. Aisle spaces, building dimensions, clearances, and facilities are determined on the plan before the layout is ready to be submitted for the approval of different members of management.

Approval of Design

This is also the point where meetings are held with the interested departments and sections to assure them that their requirements have been adequately provided for. Complete approval of the general design should be obtained before turning the job over to the draftsmen.

These meetings often involve contacts with outside suppliers of machine tools, material-handling equipment, and other facilities called for in the layout. When all the ideas about the layout have been reconciled, or as nearly so as practical, the layout is released to draftsmen for recording on drawings. In all these considerations, it is important to bear in mind that the greatest single item of manufacturing cost, material handling, is at the root of all plant layout work and should be ever recognized as a major deciding factor in designing the plan.

Converting Layouts into Floor Plans

The layout is received in template or model form from the plant layout engineers ready to be approved and drawn up in final detail on regular plant layout drawings, such as the one illustrated in Figure 49. It may also be necessary for the draftsmen to prepare the drawings of production flow charts, area allocations, bin designs, storage-rack designs, and skid designs, as well as cross-sectional and detail sketches when required for a specific layout.

The draftsmen also check the plant layout drawings with the dimensions used on the construction drawings which may be available at the time. It must be noted, however, that, since plant layout drawings must be drawn up in advance of construction drawings, the only construction drawings that may be available at this time are those prepared for former construction projects affecting the particular building involved in the present layout.

Drafting Technique

In making plant layout drawings, the draftsmen are guided by a code of standard instructions on drafting technique as regards the sizes of drawings, type

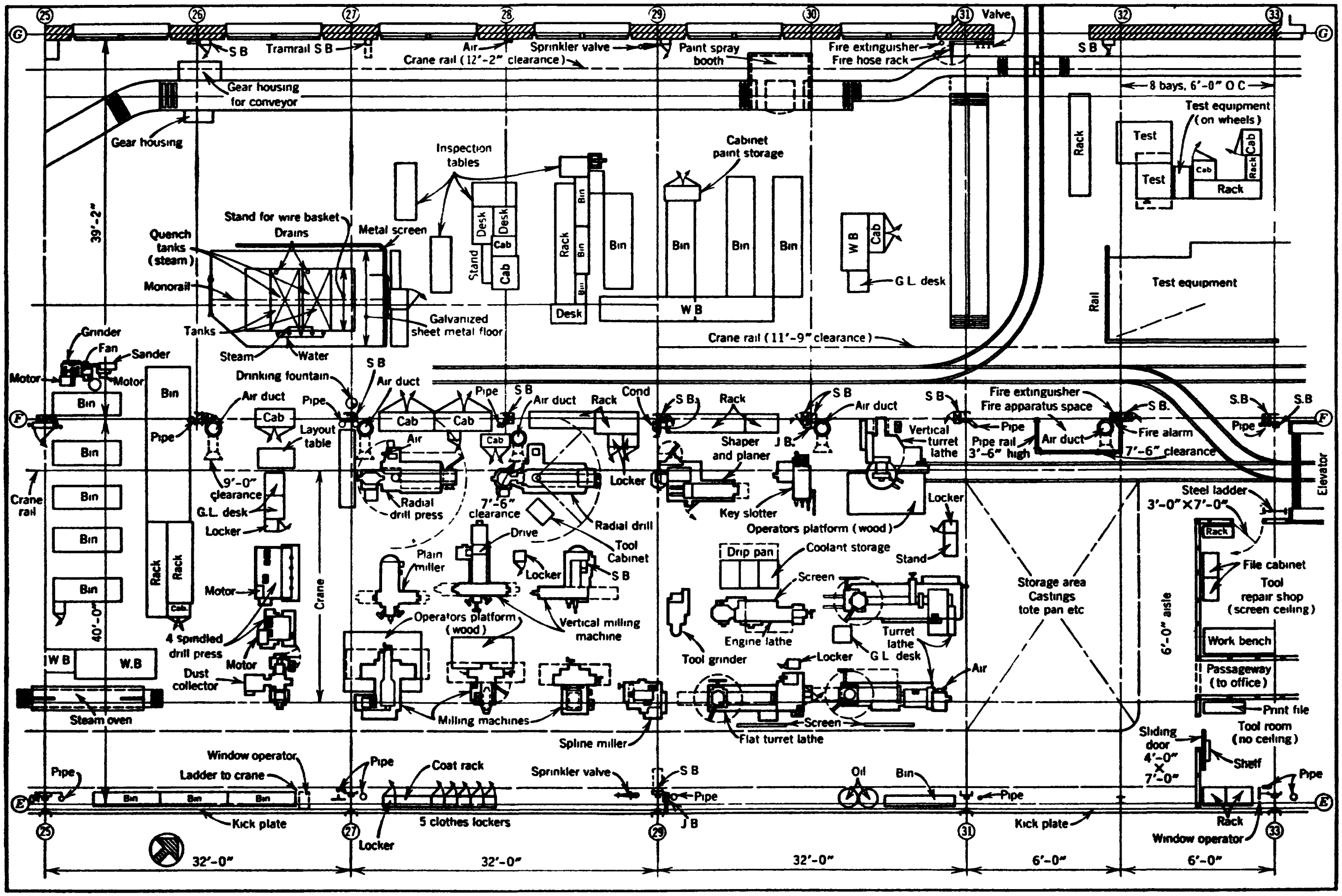


FIG. 49. *Regular plant layout drawing* prepared from template layout.

of notations, identifications, cross-references, legends, lettering, symbols, etc. Depending on the project, the draftsmen also incorporate in the floor plans of storerooms, tool cribs, and dispatch stations a complete numbering system for storage-bin compartments, floor storage areas, aisles, etc. They also identify each work station alphabetically or otherwise to permit cross-reference in summary reports covering the project.

Work Schedules

In support of all plant layout drawings, material and work schedules are prepared and are either attached to or incorporated in the plant layout drawings. A specimen form used for this purpose is shown in Figure 33, entitled "Equipment and Facilities Requirements." Complete specifications are given for each item on this schedule form. Also accompanying the drawings are perspective views and wall charts as needed.

Standard Data on Drawings

Just what information should appear on a layout drawing has not yet been prescribed in the form of standard practice. Too much drawing and too many lines tend to complicate the drawing and confuse its interpreters. Insufficient detail, on the other hand, causes unnecessary lost time and errors in reading the drawing, and wasted time in "doctoring" it up later. The minimum data which every layout drawing should contain usually include the following 14 items:

MINIMUM REGULAR DATA TO APPEAR ON ALL LAYOUT DRAWINGS

1. Title and scale of the drawing.
2. Sketch number.
3. Approval space.
4. Detail notations for use of plant engineer.
5. Construction notations for architects and detail engineers.
6. Notations on heating, lighting, ventilation, and communication facilities.
7. Directional locations and orientation on plant site.
8. Transportation and handling facilities.
9. Overhead obstructions, and obstructions below floor levels where foundations or superstructures are necessary.
10. Machine-tool and equipment identification numbers.
11. Column numbers.
12. Service outlets for gas, electricity, water, air, and other utilities.
13. Fire protection and other safety apparatus notes.
14. Signature and date.

With this information appearing on a layout drawing, the drawing can be used as a dependable guide for building design and construction and for the installation of machinery and equipment.

5. PERSPECTIVE DRAWINGS AND MINIATURE PLANTS

Perspective Drawings

In presenting a layout for the purpose of discussing arrangements with shop supervisors or with management executives, one of the most common and difficult problems is to convey a clear image of the project in the minds of all concerned, as previously pointed out. However masterful and accurate single-plane drawings may be, they inevitably lack depth and height. Architects have succeeded in overcoming much of this shortcoming through the technique of perspective drawings.

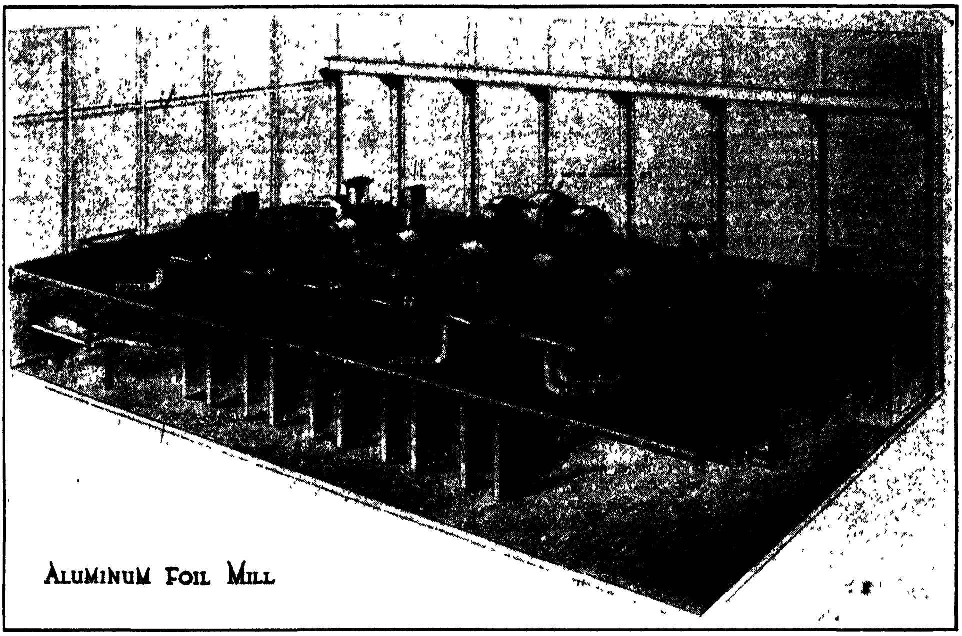


FIG. 50. *Perspective drawing* of a proposed rolling mill for aluminum foil. (*Courtesy of Westinghouse Electric Corporation, Pittsburgh.*)

A drawing of this type used for a layout of an aluminum foil rolling mill is reproduced in Figure 50. It will be observed that the floors have depth and that the stories are identified by height. The prominence given to the shape and relative size of the machinery and equipment is worthy of especial note. One can perceive readily the continuous strip of aluminum foil actually traveling through the battery of five roll stands, from uncoiler to winding reel.

Three-Dimensional Presentations

The outstanding advantage that a perspective drawing possesses over a flat, one-plane, conventional layout drawing is the clear, three-dimensional image it presents to the observer. Many of the plants illustrated in trade magazines and advertising literature are merely perspective drawings, and not photographs as might be supposed by some, notwithstanding their realistic appearance. The effect of reality thus obtained in publications of this type can be used to considerable advantage by the plant layout engineer in presenting a layout project.

Cost of Sketches and Models

The cost of producing a perspective drawing is usually much less than that of a miniature model of the layout. While not so flexible as the model for the purpose of reshifting the arrangement during the development stage, the perspective drawing nevertheless provides a realistic presentation of almost equal merit to that of the miniature model. This feature is of extreme importance in endeavoring to present a layout wherein the arrangement of the machinery and equipment is governed largely by the mechanical design of the process. Quite often rough-drawn three-dimensional sketches, similar to those employed in many war plants to train operators, are valuable aids for illustrating layout plans.

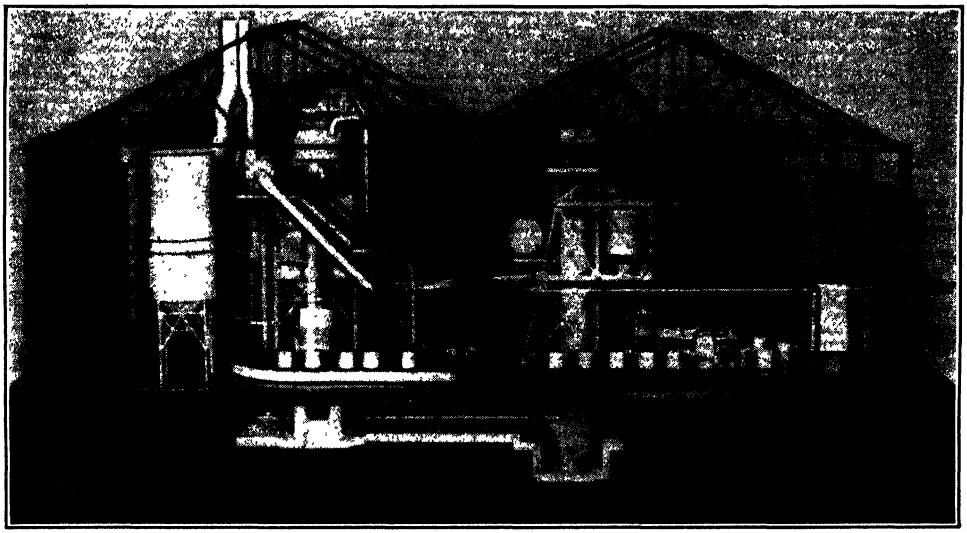


FIG. 51. *Miniature plant.* Application of three-dimensional scale model for the layout of an automatic molding and casting installation in a foundry. (*Courtesy of Westinghouse Electric Corporation, Pittsburgh.*)

Miniature Plants

The medium generally considered and acclaimed as the best developed thus far for providing ready visualization of a layout project is the miniature plant. This is a three-dimensional model generally made to the scale of ¼ inch = 1 foot. In Figure 51 is shown a miniature plant for the layout of an automatic molding and casting installation in a foundry. An attempt to make a plan view of this installation on an engineering drawing, for the purpose of providing a clear image of the project, would of necessity result in an unintelligible maze of intersecting lines.

For the project illustrated here, the model was actually used for planning and installation purposes. The detail layout drawings were used only for the fabrication and erection of the equipment superstructure. In some industries, the complicated design of equipment often makes the plant layout drawing confusing even to the draftsman who prepared it. This is notably true of foundries, distillation plants, refineries, and chemical plants. For these industries, models are exceptionally helpful in plant layout work.

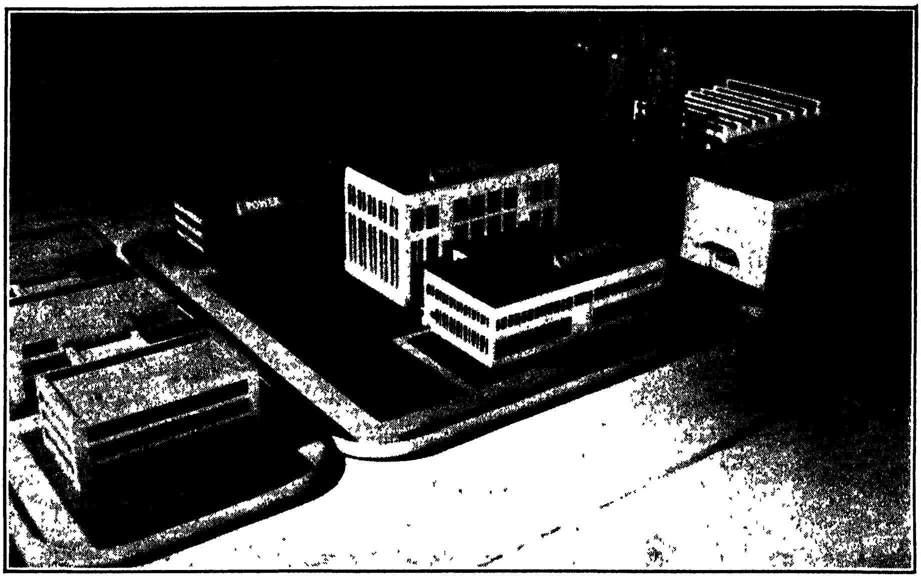


FIG. 52. *Atomic power plant of the future* conceived by the Kellex Corporation, New York, subsidiary of the M. W. Kellogg Company, Jersey City, engineers of the K-25 plant at Oak Ridge, Tenn., for the production of U-235 for the atom bomb. The miniature display pictured above was three months in the making. In the foreground is the Nuen (Nuclear Energy) Reactor, or pile building, with the processing structure behind it and the power unit in the background. A laboratory is shown in the right foreground, and the manufacturing plant is at the extreme right in the background. (*By permission of the Atomic Energy Commission.*)

Multiple-Building Models

For a plant consisting of several detached buildings, the three-dimensional miniature model provides a bird's-eye view of the entire plant premises such as could not be approached, even remotely, on flat drawings. The model shows the structural design of the entire group of buildings, as illustrated in Figure 52 for an atomic power plant of the future. The building models are grouped into a miniature display clearly revealing the relative height, depth, and interbuilding spacing for the entire plant premises.

PART 2 · PLANNING THE PROCESSING DEPARTMENTS

CHAPTER VII

Framework of Plant Layout Procedure

Objectives of Plant Layout Engineering

Plant layout engineering, as the name implies, is the scientific planning, designing, and installing of plant facilities. This description applies equally to the arrangement of new plants and the rearrangement of existing establishments. In more specific terms, plant layout engineering consists of placing the right equipment in the proper place, to permit the processing of a product or part in the most efficient manner, through the shortest distance of travel, and in the quickest time attainable. Without a thorough, preparatory analysis and study of the various factors giving rise to the need for a plant layout, the conditions set forth in the objectives of plant layout engineering would fall short of realization, except perhaps in extremely simple cases, such as relocating a small work bench.

Although plant layout engineering is relatively new as a science and its acceptance as a vital tool of management has been heretofore confined to the more progressive enterprises, its basic principles are over 160 years old. The technique of planning floor layouts dates back to colonial days when grist-mill machinery was largely built in as a part of the plant structure and was linked from floor to floor by common transmission belts (see Figure 6).

Practical Aspects of Layout Work

The preliminary steps leading to the justification for the effort and cost of developing a plant layout were considered in Part 1. The practical aspects of plant layout engineering are taken up in Part 2 for processing departments, and in Part 3 for service departments.

The material contained in Parts 2 and 3 of this book is made up of accepted standard practices tested in the engineering departments of leading American industries of varying sizes and types. Many new developments in plant layout were put into practice in war industries during World War II, and new approaches will no doubt be discovered during the next several decades, so long as plant rehabilitation remains a country-wide endeavor. This book attempts to bring together the proved best practices of today.

1. SOURCES AND FLOW OF FUNDAMENTAL LAYOUT DATA

Eight Categories of Plant Layout Data

In formulating tentative layout plans, the maze of technical, performance, and cost data that must be assembled, analyzed, and reconciled was discussed briefly in Chapter IV. The full scope of this information may be classified into the following eight major categories:

A. **Intangible factors** of marketing aspects and production forecasts.
B. **Production data** on component parts, operations, and machine loads.
C. **Existing field data** on buildings, grounds, services, and utilities.
D. **Layouts of existing production facilities,** services, and utilities.
E. **Flow charts** of existing and proposed manufacturing methods.
F. **Actual template layouts** and operating costs of tentative plans.
G. **Cost information** in the form of statements, records, and ledgers.
H. **Financial factors** studied in selecting one of several proposals.

Flow of Plant Layout Data

The sources, sequence, and interrelationship of these eight major classes of fundamental layout data are graphically summarized in the flow chart in Figure 53. The **intangible factors** provide the production forecast which forms the basis for determining the **production data** needed in drawing up the **flow charts** for the contemplated volume of production. While this information is being compiled in the production engineering department, the plant engineering department is preparing the **existing field data** required as the basis for preparing the **layouts of existing production facilities** in the case of plant rearrangement or additions.

By combining these five classes of data on flow charts, an area allocation diagram can be developed as the basis for setting up the **actual template layouts** of tentative plans that suggest themselves during these preliminary stages of analysis and summation. At this point, the **cost information** obtained from the accounting department is applied to arrive at fully appraised proposals in terms of the **financial factors** to be considered by the general administrative department.

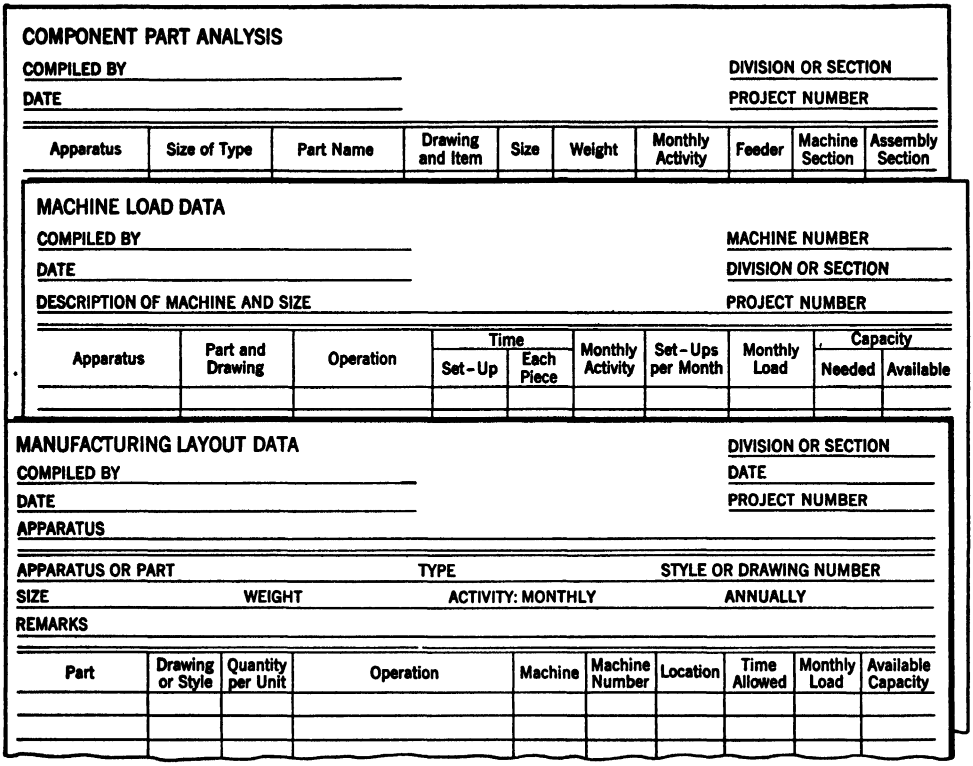
Selection of the Best Plan for Development

After rough preliminary estimates for a number of alternative layout plans and a careful survey of the statistical records discussed in Chapter IV have justified the development of tentative layout plans for further consideration, the actual work of fully exploring the possibilities of the tentative project is undertaken on a planned basis. The more exhaustive data, forms, plans, charts, sketches, drawings, and specifications itemized in Figure 53 are gathered from the indicated sources simultaneously and are resolved into a number of final proposals from which the management selects one layout plan for execution.

It is not until this stage has been reached that management can properly decide on one of the several plans presented. Furthermore, it is not until a specific plan has been finally selected that the execution of actual layout work can begin. The remaining pages in this chapter are devoted to the procedure for gathering the basic layout data and for designing and appraising the tentative plans preceding the actual development of the selected layout plan. The actual development of the particular layout plan selected from these preliminary alternatives forms the contents of the remaining chapters in this book.

Intangible Factors of Marketing

The treatment of the intangible factors of marketing aspects and production forecasts has been covered in Chapter IV, "Basis for Designing a Plant Layout." The future behavior of the market, the technological developments to anticipate, and the changes in product design to take into consideration are matters that a company faces continually. The proper measurement of these factors determines for years to come the degree of success to be attained from a contemplated change in plant layout.



COMPONENT PART ANALYSIS

COMPILED BY

DIVISION OR SECTION

DATE

PROJECT NUMBER

Apparatus	Size of Type	Part Name	Drawing and Item	Size	Weight	Monthly Activity	Feeder	Machine Section	Assembly Section

MACHINE LOAD DATA

COMPILED BY

MACHINE NUMBER

DATE

DIVISION OR SECTION

DESCRIPTION OF MACHINE AND SIZE

PROJECT NUMBER

Apparatus	Part and Drawing	Operation	Time		Monthly Activity	Set-Ups per Month	Monthly Load	Capacity	
			Set-Up	Each Piece				Needed	Available

MANUFACTURING LAYOUT DATA

DIVISION OR SECTION

COMPILED BY

DATE

DATE

PROJECT NUMBER

APPARATUS

APPARATUS OR PART

TYPE

STYLE OR DRAWING NUMBER

SIZE

WEIGHT

ACTIVITY: MONTHLY

ANNUALLY

REMARKS

Part	Drawing or Style	Quantity per Unit	Operation	Machine	Machine Number	Location	Time Allowed	Monthly Load	Available Capacity

FIG. 54. *Representative data forms* frequently used by plant layout engineers in gathering production information from the production engineering department. These forms are described fully in Figures 65, 66, and 68.

2. PRODUCTION DATA ON PARTS, OPERATIONS, AND MACHINES

Production Analysis

Before a layout of production facilities can be started, a thorough production analysis must be made to determine manufacturing requirements. To make this analysis, the operations must be known in their proper sequence, on each type of production facility and for each kind of product to be manufactured.

Production Forms

The three types of forms found generally suitable for gathering the production data needed for a plant layout are illustrated in Figure 54. Some layout projects, because of their scope, require the use of all three of these forms, whereas only one or two may be needed to compile the production data needed on some of the simpler projects. All this information is recorded for future reference in a data book which becomes a permanent record of the project.

Production Data

The seven basic steps through which the production data for an entire plant are gathered for adaptation to a layout project are essentially the same for most types of plants. (See Section *B* in Figure 53.)

Questions to Be Answered

In gathering the production data, the plant layout engineer consults with managers, design engineers, supervisors, manufacturing engineers, foremen, time-study men, etc., with a view to securing answers to such questions as:

1. What are the products?
2. Are any design changes contemplated?
3. What is the rate of the present production?
4. What production output is wanted?
5. How long will the activity last?
6. How much flexibility should the layout have?

3. EXISTING FIELD DATA ON BUILDINGS, GROUNDS, AND SERVICES

While production data are being compiled from production engineering department records, field data on existing buildings and grounds, together with service department facilities and plant utilities, are secured from the plant engineering department.

Layout of Plant Site

A small-scale layout of the entire site is made for the purpose of working out a general flow of materials between departments. On this plan are shown all shops and departments, with the amount of floor area occupied by each. Figure 55 illustrates a skeleton floor plan, 1 inch = 40 feet, of a machining and assembly plant. (See also Figure 59.)

An actual site inspection is made to determine if the utilities are located exactly as shown on the drawings. It is a source of no little embarrassment to locate an outbuilding on a plot plan, only to find out later that the foundation of this building falls directly over a main sewer line or interferes with other existing structures.

Checking Building Dimensions

If detail plans of the building structure are not available, it is necessary to make measured drawings of these buildings and show thereon all existing services and utilities. These drawings do not contain machine tools or manufacturing equipment. Building dimensions on architects' drawings must be checked carefully because all dimensions on drawings are seldom correct unless verified in the field after construction. Likewise, every building detail, such as columns, windows, and doors, must be checked against the drawings for actual location and size.

Building heights must be checked accurately to provide assurance that trusses and girders will clear all contemplated traffic and working equipment. The strength of the building trusses must also be ascertained in order to know exactly where monorails or cranes may be installed. Floor construction, allowable floor loading, pits, and machine foundations are also matters to ascertain at the outset. To insure access from one building to another, main traffic aisles are laid out before actual layout work is begun, as it is much more difficult to place the aisles later.

Another point to ascertain at the start is whether the utilities are to be brought in overhead or under the floor.

Master Plans of the Building

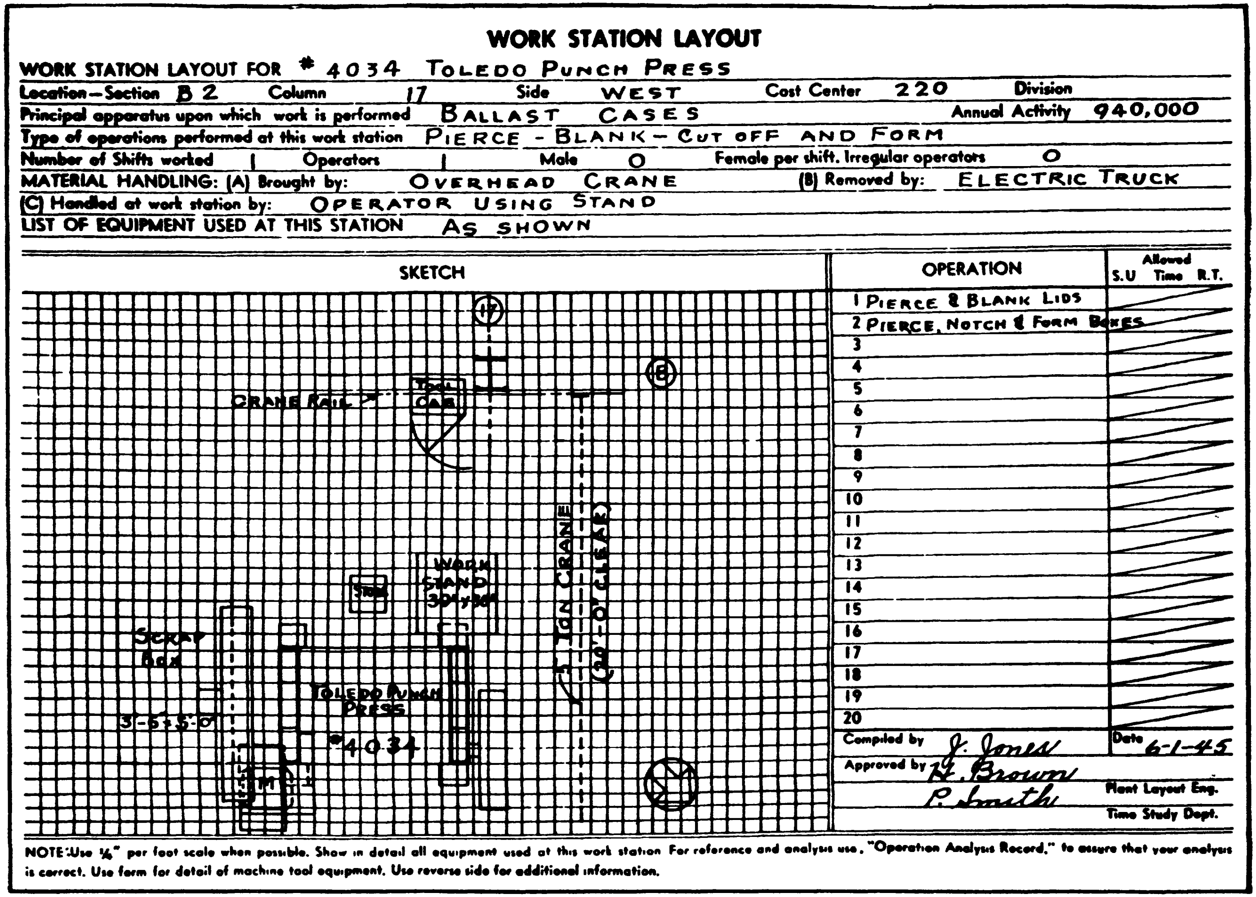
After the building floor plans have been completed and checked for dimensions and building detail, and all service facilities and plant utilities have been fully incorporated on the drawings, the plans are drawn in ink on tracing cloth to a scale of ¼ inch = 1 foot. These tracings become a permanent record of the building apart from the drawings subsequently made of the layout. All layout drafting is done *on reproductions* of these master plans of the building.

4. LAYOUTS OF EXISTING PRODUCTION FACILITIES AND SERVICES

In laying out existing production facilities, work stations, and operations, the various drawings prepared from the data on existing machinery, equipment, and operations are enumerated in Figure 53, Section *D*.

Accuracy of Data on Existing Layout

Layouts of existing production facilities record all machine tools and auxiliary equipment as they exist before any changes are made for the new layout. These layouts enable the plant layout engineer to analyze the existing flow of production and help him determine where improvements are to be made. Later, when the new layout is completed, comparisons between the old layout and the new layout can readily be made to point out the advantages of the new layout. The importance of the accuracy of this record becomes apparent when it is realized that much of the success in designing the new layout depends on the accuracy of the data shown on drawings of the existing layout.



WORK STATION LAYOUT

WORK STATION LAYOUT FOR # 4034 TOLEDO PUNCH PRESS

Location—Section B 2 Column 17 Side WEST Cost Center 220 Division

Principal apparatus upon which work is performed BALLAST CASES Annual Activity 940,000

Type of operations performed at this work station PIERCE - BLANK — CUT OFF AND FORM

Number of Shifts worked 1 Operators 1 Male 0 Female per shift. Irregular operators 0

MATERIAL HANDLING: (A) Brought by: OVERHEAD CRANE (B) Removed by: ELECTRIC TRUCK

(C) Handled at work station by: OPERATOR USING STAND

LIST OF EQUIPMENT USED AT THIS STATION AS SHOWN

SKETCH

OPERATION	Allowed S.U Time	R.T.
1 PIERCE & BLANK LIDS		
2 PIERCE, NOTCH & FORM BOXES		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		
18		
19		
20		

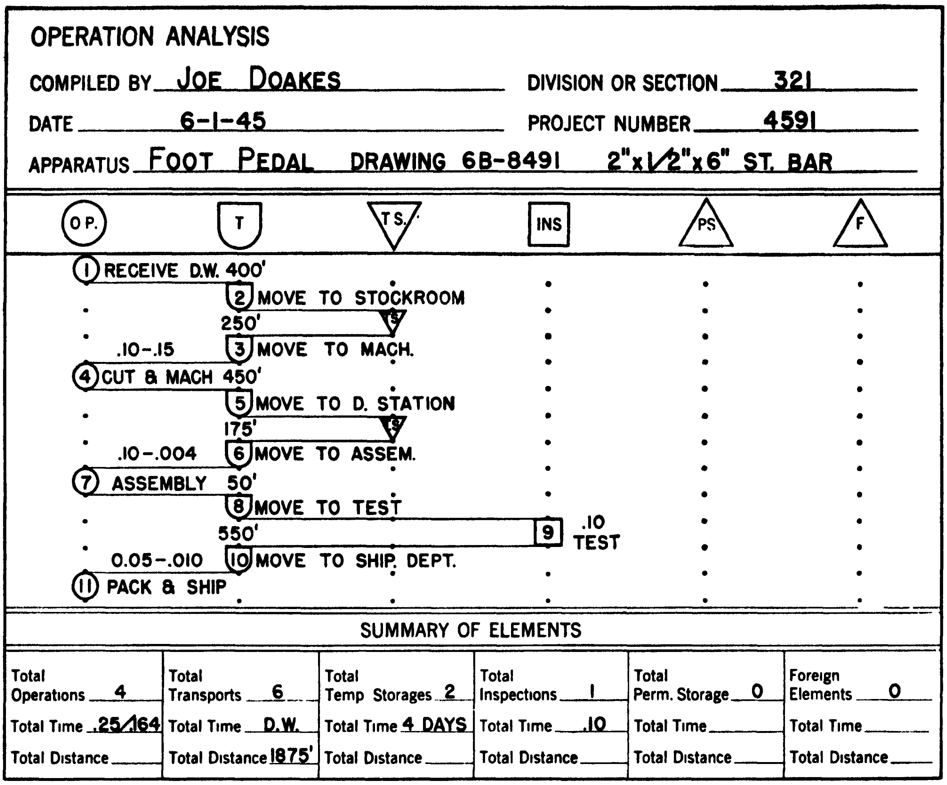
Compiled by J. Jones Date 6-1-45

Approved by H. Brown Plant Layout Eng.

P. Smith Time Study Dept.

NOTE: Use ¼" per foot scale when possible. Show in detail all equipment used at this work station For reference and analysis use, "Operation Analysis Record," to assure that your analysis is correct. Use form for detail of machine tool equipment. Use reverse side for additional information.

FIG. 56. *Work-station layout* for single units of machinery and equipment involved in the new plant layout project. This layout allows for the travel area of all moving parts of each machine and for auxiliary equipment used at the work station.



OPERATION ANALYSIS

COMPILED BY JOE DOAKES DIVISION OR SECTION 321

DATE 6-1-45 PROJECT NUMBER 4591

APPARATUS FOOT PEDAL DRAWING 6B-8491 2"x1/2"x6" ST. BAR

SUMMARY OF ELEMENTS

Total Operations 4	Total Transports 6	Total Temp Storages 2	Total Inspections 1	Total Perm. Storage 0	Foreign Elements 0
Total Time .25/.164	Total Time D.W.	Total Time 4 DAYS	Total Time .10	Total Time	Total Time
Total Distance	Total Distance 1875'	Total Distance	Total Distance	Total Distance	Total Distance

FIG. 57. *Flow and sequence of all operations for a part.* This analysis also shows the time and distance between each element Statistics for this flow are obtained from form in Figure 75.

5. FLOW CHARTS OF EXISTING AND PROPOSED MANUFACTURING METHODS

General Review of Existing Conditions

The data gathered thus far may be summarized under four main headings:

A. Intangible factors of marketing aspects.
B. Production data on existing facilities.
C. Existing field data on buildings and grounds.
D. Layouts of existing production facilities.

Aside from the production forecast, which has not yet been used, all the data gathered and analyzed down to this point consist of a general review of existing conditions. Or, in other words, no information has been added beyond what already exists in actuality. No attempt has been made yet to peer into the possible benefits of, or the requirements for, a new layout.

In the step about to be discussed, namely, the development of flow charts of existing methods, suggestions are given for improvement in existing methods. This opens the door to the possibilities of a new plant layout. In loading the contemplated production schedules on existing production facilities through the medium of these flow charts, the necessity for additional machinery and equipment is disclosed.

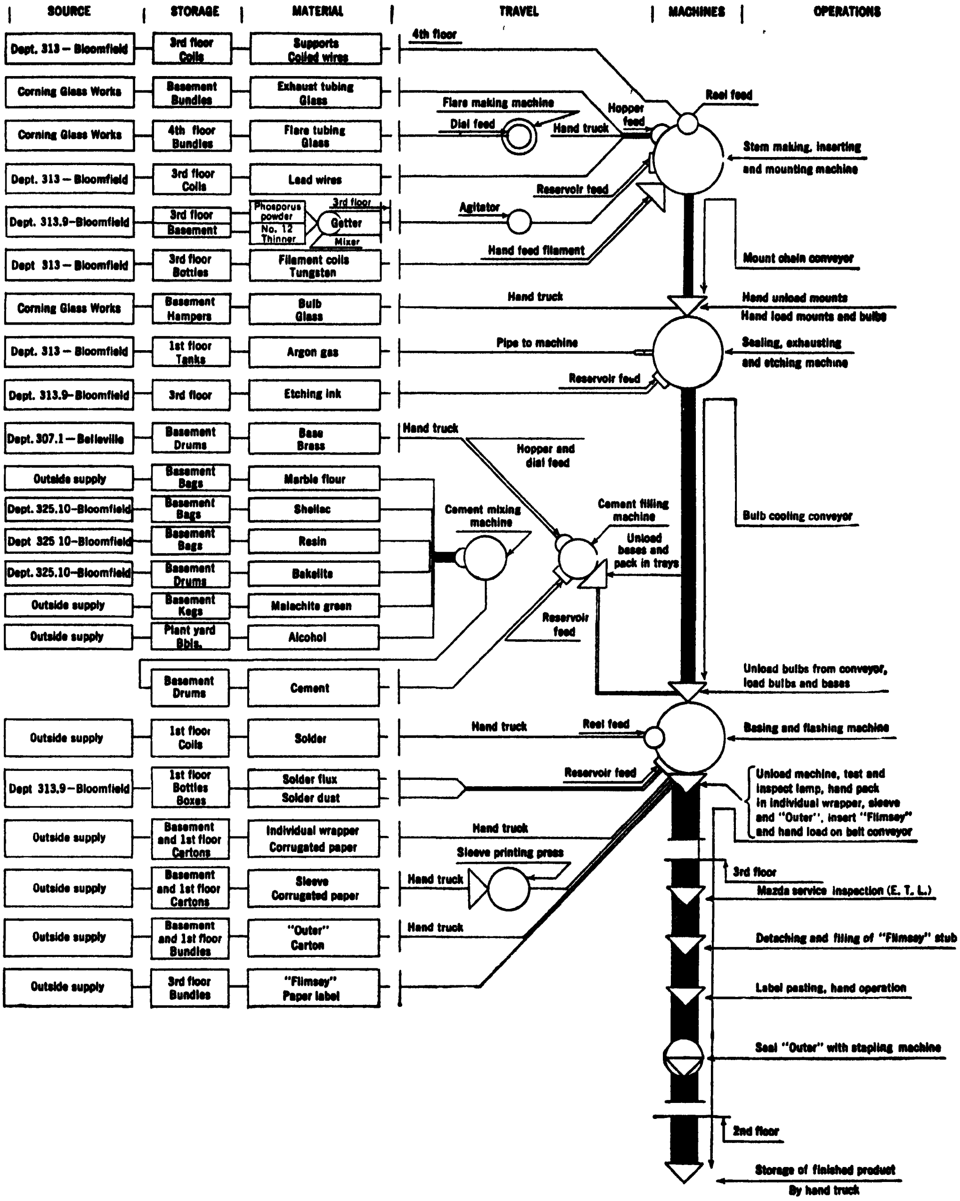


FIG. 58. *Production flow chart* of materials, through machines, by operations, to manufacture a 60-watt incandescent lamp. (*Courtesy of Westinghouse Electric Corporation, Pittsburgh.*)

Crucial Stage in Plant Layout Development

The arrangement of existing facilities to best suit contemplated production requirements, and the selection and strategic arrangement of any additional production facilities to fully meet these requirements, strike at the very core of plant layout engineering. It is at this stage of plant layout work that practical experience and sound judgment in plant layout engineering reach their most crucial stage. The decisions and recommendations the plant layout engineer is called upon to make determine for years to come the production efficiency inherent to the tentative layout plan later selected for execution.

Development of Flow Charts

A synopsis of the use made of existing and projected data in developing flow charts is given in Figure 53. The technique employed in the actual development of these charts is described at length in Chapters VIII and IX of this book.

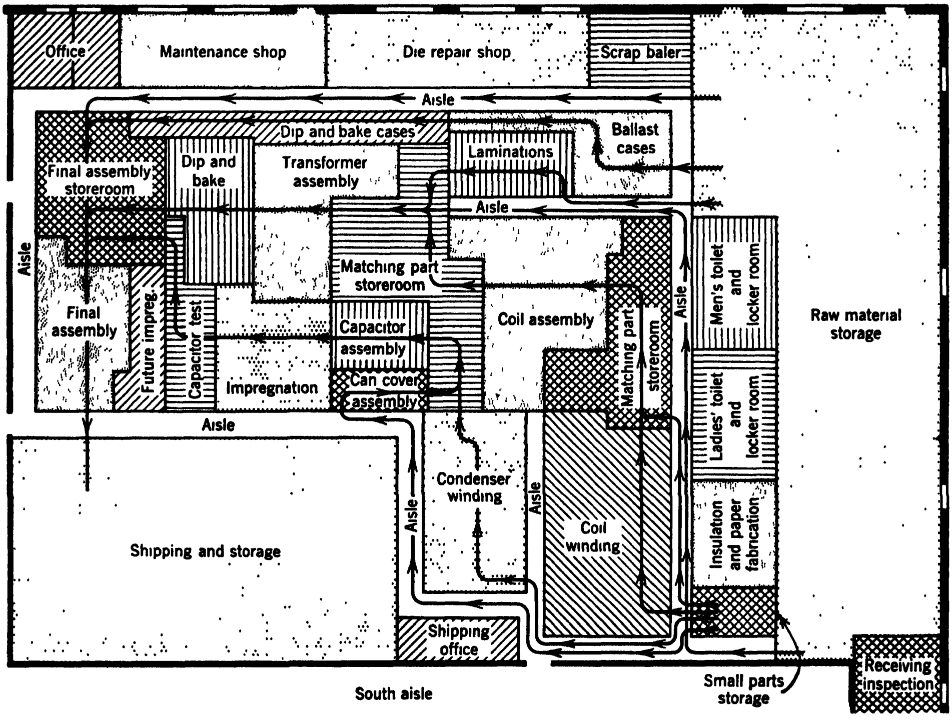


FIG. 59. *Area allocation diagram.* Schematic plan of preliminary area allocation and product flow through the plant is invaluable in determining the logical relationship of departments and the flow of materials and product through them. This chart serves as a nucleus around which the preliminary template layouts can be made.

Layout Factors Determined from Flow Charts

By means of colored strings or lines on production flow charts, actual product travel can be shown and measured for tabulation. Distances traveled on the new layout can be compared to the same travel on the existing layout, and definite savings can be determined. Other layout factors developed as the plan progresses include material-handling equipment, aisle spaces, dispatch areas, raw-material space, matching centers, service centers, shop offices, and provisions for expansion.

6. ACTUAL TEMPLATE LAYOUTS AND OPERATING COSTS OF TENTATIVE PLANS

Preliminary New Layout

When all the preliminary steps outlined prior to this stage have been taken and a course of action has been fairly well determined, the first actual template may now be started for the project. In proceeding with the new layout, the plant layout engineer follows the plan outlined in Figure 53, Section *F*.

After the placing of the templates of the layout in what appears to be the best possible arrangement to meet the requirements of the data compiled for the project, this preliminary layout is carefully analyzed for possible improvements. The improvements finally decided upon are incorporated into the layout before drawings of the layout are made.

Equipment and Facilities Requirement Schedule

To simplify the task of the construction estimators and of the installers of the new layout, the plant layout engineer also prepares a form known as an equipment and facilities requirement schedule, such as illustrated in Figure 33. This schedule lists in columnar form each item shown on the detailed drawings and specifies all the information on facilities required to complete the installation for each item. Use of this schedule not only minimizes the possibility of error or oversight in actual installation but also saves much time and effort during installation. The schedule also permits the construction estimator to figure the cost of such items as power loads and service facilities.

Selection of the Best Layout Plan

The best layout for a project is ultimately gauged on the operating economy it provides as against the amount of initial investment required. Other limiting factors entering into the selection of the best plan out of several possibilities are:

a. The physical limits of the site.
b. The aim to provide adequate facilities to produce all the desired output and to do so with the least amount of material-handling and processing costs.
c. Generous provision for future expansion.
d. Flexibility of layout design which will lend itself to frequent rearrangement as future necessity may demand.
e. The highest amount of immediate and potential net profit from the business while the cost of installing the project is being absorbed.
f. The permanency of the installation.

The layout that may be ideal from the factory standpoint is often abandoned when it is found to fall short of one or more of these broad factors.

7. COST INFORMATION AND FINANCIAL FACTORS FOR EACH PROPOSAL

Objectives of the Layout

The final decision in the selection of a layout proposal out of a number of alternative plans cannot be made on a sound basis without first studying the costs, operating as well as construction, of the layout, nor without making a comparison of the net profits accruing from each plan. For, in the final analysis, the company is in business primarily to make money, and it is the return on the projected investment which will determine the justification for the layout. The relative savings and net profit under each plan will also influence the decision as to the type of layout which will be most suitable from both a financial and an operation standpoint.

In situations where the motivating objective of the new layout is to improve present manufacturing activities rather than to provide for an expansion in output, the proposed project must yield enough savings to pay for the cost of installation, including obsolescence on existing machinery and equipment which may be retired, within a period not usually exceeding three years, depending upon the size of the installation. Projects involving the expenditure of considerable sums of money are normally allowed a longer amortization period than those of small commitment. The practice in most progressive companies is not to wait until a major investment is involved before modernizing a layout, but to keep abreast of latest improvements by rearranging the layout more frequently, and on a basis of self-amortization within a period varying from one to two years, depending upon the degree of competition existing within the particular industry of which the company is a member.

Approach to Final Appraisal

The approach to the financial appraisal of a proposed layout is summarized in Figure 53, under *G*, Cost Information, and *H*, Financial Factors.

Actual Plans for a Foundry

An illustration of an actual development of six alternative plans in a foundry to provide added plant capacity for a forecasted increase in sales volume is shown in Figure 60. The six plans proceed progressively from an investment of $711,270 to rehabilitate existing facilities up to an investment of over ten times that amount to construct a new plant. The resulting net profit for the first five years under each of the first five plans increases progressively from 8.2% up to 38.7% before considering the erection of a new foundry. A point to note in particular is that the resulting net profit under plans 3, 4, and 5 increases gradually from year to year, and that the ultimate measure of net profit on all plans is not soundly comparable until it has been applied to the accumulated volume of sales for the first five years of operation.

NAMELESS FOUNDRY COMPANY INVESTMENT AND PROFIT PLANS TO PROVIDE PLANT CAPACITY FOR FORECASTED VOLUME

DESCRIPTION	NORMAL Normal Year with Present Lines of Products	PLAN 1 Minimum Inevitable Rehabilitation (Deferred Maintenance)	PLAN 2 To Remove Present Overload from Heavy Castings	PLAN 3 To Increase Production Volume of Extra Heavy Castings	PLAN 4 To Increase Extra Heavy Castings and Add Forged Units	PLAN 5 To Carry Out Plan 4 and Extend Plant into Larger Area	PLAN 6 To Build an Entire New Plant and Sell the Existing One
	A. NEW CAPITAL INVESTMENT UNDER EACH PLAN						
REMODEL EXISTING PLANT							
New foundry building		$536,920	$536,920	$536,920	$536,920	$536,920	
New service building		174,350	174,350	174,350	174,350	174,350	
New 100-ton cranes			310,200	310,200	310,200	310,200	
Extend 3 buildings				456,720	456,720	456,720	
New forge shop					623,700	623,700	
Acquire land for future expansion						200,000	
BUILD ENTIRE NEW PLANT							
Sell existing land and buildings and write off unrealizable net book value							$2,039,782
Acquire land, construct buildings, and replace immobile equipment							5,751,854
Total investment under each plan		$711,270	$1,021,470	$1,478,190	$2,101,890	$2,301,890	$7,791,636
	B AMOUNT OF NET PROFIT UNDER EACH PLAN						
			First Year				
Net sales	$ 8,148,146	$ 8,148,146	$ 8,148,146	$10,450,706	$12,086,706	$12,086,706	$12,086,706
Cost of sales	6,650,992	6,650,992	6,650,992	7,664,074	7,925,136	7,925,136	
Deductions from gross profit	775,934	799,232	811,320	824,646	848,554	857,594	
Moving expense, etc , in first year	——	128,800	136,800	260,400	260,400	260,400	
Net profit, amount	721,220	569,122	549,034	1,701,586	3,052,616	3,043,576	
percent	8.9	7.0	6.7	16.3	25.2	25.2	
			Second Year				
Net sales	$ 8,148,146	$ 8,148,146	$ 8,148,146	$10,834,466	$14,106,466	$14,106,466	$14,106,466
Cost of sales	6,650,992	6,650,992	6,650,992	7,812,414	8,256,750	8,256,750	
Deductions from gross profit	775,934	799,232	811,320	828,646	856,554	865,594	
Net profit, amount	721,220	697,922	685,834	2,193,406	4,993,162	4,984,122	
percent	8.9	8.6	8.4	21.9	35.4	35.3	
			Third Year				
Net sales	$ 8,148,146	$ 8,148,146	$ 8,148,146	$11,218,226	$16,126,226	$16,126,226	$16,126,226
Cost of sales	6,650,992	6,650,992	6,650,992	7,960,754	8,588,364	8,588,364	
Deductions from gross profit	775,934	799,232	811,320	832,646	864,554	873,594	
Net profit, amount	721,220	697,922	685,834	2,424,826	6,673,308	6,664,268	
percent	8 9	8 6	8.4	21.6	41.4	41.3	
			Fourth Year				
Net sales	$ 8,148,146	$ 8,148,146	$ 8,148,146	$11,601,986	$17,327,986	$17,327,986	$17,327,986
Cost of sales	6,650,992	6,650,992	6,650,992	8,109,094	8,919,982	8,919,982	
Deductions from gross profit	775,934	799,232	811,320	836,646	872,554	881,594	
Net profit, amount	721,220	697,922	685,834	2,656,246	7,535,450	7,526,410	
percent	8.9	8.6	8.4	22.9	43.5	43.4	
			Fifth Year				
Net sales	$ 8,148,146	$ 8,148,146	$ 8,148,146	$11,985,746	$17,711,746	$17,711,746	$17,711,746
Cost of sales	6,650,992	6,650,992	6,650,992	8,257,434	9,068,322	9,068,322	
Deductions from gross profit	775,934	799,232	811,320	840,646	880,554	889,594	
Net profit, amount	721,220	697,922	685,834	2,887,666	7,762,870	7,753,830	
percent	8.9	8.6	8.4	24.1	43.8	43.8	
			Total Five Years				
Net sales	$40,740,730	$40,740,730	$40,740,730	$56,091,130	$77,359,130	$77,359,130	$77,359,130
Cost of sales	33,254,960	33,254,960	33,254,960	39,803,770	42,758,554	42,758,554	
Deductions from gross profit	3,879,670	4,124,960	4,193,400	4,423,630	4,583,170	4,628,370	
Net profit, amount	3,606,100	3,360,810	3,292,370	11,863,730	30,017,406	29,972,206	
percent	8.9	8.2	8.1	21.2	38.8	38.7	

Six progressive financial alternatives in re-arranging a foundry to meet projected sales requirements. Note that new investment for expansion in plans 3, 4, and 5 consists largely of inevitable rehabilitation required in plans 1 and 2 to continue current volume. Compare total 5-year net profit at foot of table with investment requirement in top section. Using plan 3 as an example, by investing $1,478,190 in remodeling the existing plant, the net profit for 5 years amounts to $11,863,730 as against $3,606,100 under existing conditions. This amounts to collecting $8,257,630 over 5 years for investing $1,478,190.

FIG. 60.

The Profit Incentive of a Plan

The financial principles involved in this particular case apply with equal impact to either smaller or larger plants. The profit incentive remains the dominant factor in most industrial enterprises, and the return on the investor's dollar recognizes no size in the establishment. The determining factors from the investor's viewpoint, or from the viewpoint of the man who has the final jurisdiction over the authorization of the layout project, may be summed up as:

1. The stability and dependability of the market for the output of the plant.
2. The reality and amount of the resulting net profit obtainable from the project.
3. The ability of the company to finance the undertaking without jeopardizing its financial structure.

When these three factors have been properly analyzed and appraised, and the indicated savings and net profit substantiated as being safely within the range of achievement, little if any difficulty should stand in the way of securing approval to execute the plan, even though the company may have to borrow the funds needed to finance the project.

CHAPTER VIII

Determining the Capacities for the Design

1. DURATION AND PRECISION OF A PLANT LAYOUT DESIGN

Probable Duration of a Product

The life of a product design is not ordinarily a matter of someone's guess. Careful market research, knowledge of product-design trends, familiarity with fundamental research development in new materials and scientific discoveries, interpretation of consumer preferences, price and market surveys, profit margins, and competitors' activities, plus a modicum of plain, common horse sense, have much to do with estimating the probable economic life of a product design. Only too often, major decisions concerning the probable duration of a design are reached as the result of 5-minute round-table discussions of trivial details instead of data based on factual information. When genuine scientific research into the economic expectancy of the duration of a market demand for a product design is expertly conducted, the product is often redesigned, or even discarded completely, long before intolerable losses are suffered from the installation of an unjustifiable but commandeered plant layout revised to accommodate the fantastic claims of a new product design.

Normal Life of a Plant Layout

The experience of countless intermittent manufacturing establishments in the metal-trades industries is that 3 years is the normal life of a departmental layout design. During this 3-year interval, enough technological advances normally occur in manufacturing methods and product design to warrant a restudy of the plant layout design. A change in layout design may be made mandatory at that time as the result of changes in market demands; improvements in product design; redesign of product imposed by the necessity to reduce costs; the introduction of new materials, new manufacturing methods or new production equipment; changes in labor relations; or the need of plant rehabilitation to keep abreast of progress in modern factory methods.

Insuring a Layout Against Failure

Without doubt, the principal cause of failure of plant layout plans to yield the expected results is the inadequacy of the fundamental data. A plant layout can be, and should be, designed with the same degree of accuracy as a machine or a building structure. Definite engineering principles and factual data basically govern the design of electrical or mechanical apparatus and building construction. Similar, although perhaps more rigid, specifications should surround and determine the efficiency of a plant-layout design. Ignorance of these laws, principles, and recognized fundamentals of plant layout engineering inevitably leads only to makeshift and inefficient layout designs which result in endless excessive operating costs, if not in the outright but often unjustifiable "throwing out" of a good line of products. See Figures 61 and 62 for an illustration of tailoring the layout to fit the problem.

FIG. 61. *Variety of sizes.* Careful consideration has to be given to the variety of sizes of a product in determining the projected output. Otherwise the processing and handling of the product may gravitate to the manual methods indicated here for storing motor stators.

Primary Objectives of a New Layout

The first step in the preparation of analytical data for the determination of the capacity for a layout design is the calculation of the output capacity. At this point, however, it is assumed that the preliminary steps to ascertain the need of a layout, as described in Chapters II and IV, have already been taken, and that a decision has been reached to justify the work entailed in designing a layout. In selecting and analyzing supporting data for a plant layout a simple but effective rule-of-thumb for the engineer is the answer to such basic questions as: What? Why? Where? When? and How Many?

1. What? Nature of the product.
2. Why? Purpose of the layout.
3. Where? Plant site, location, or existing department.

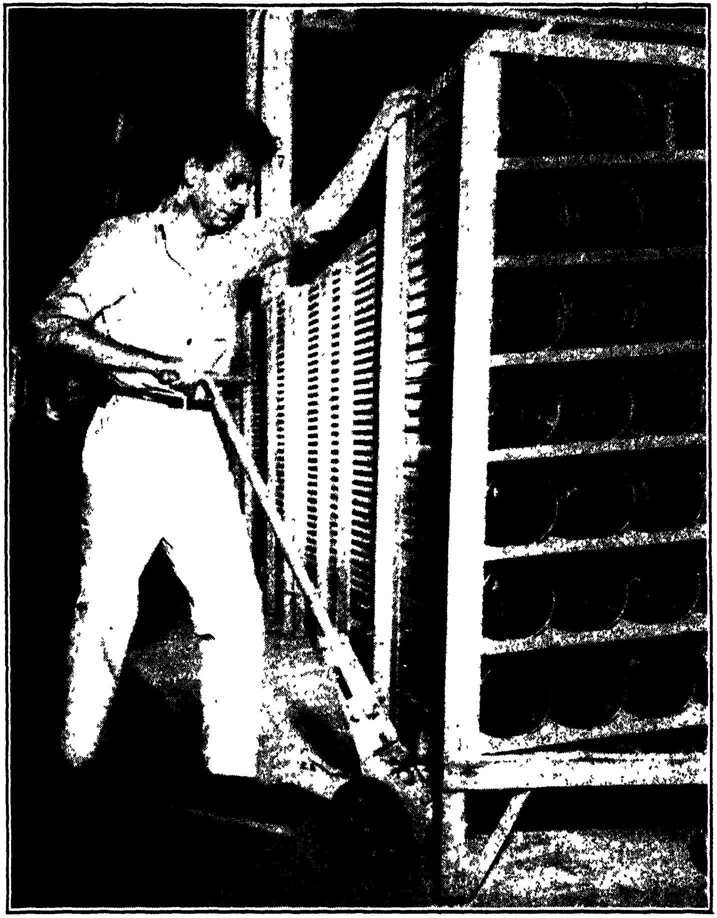
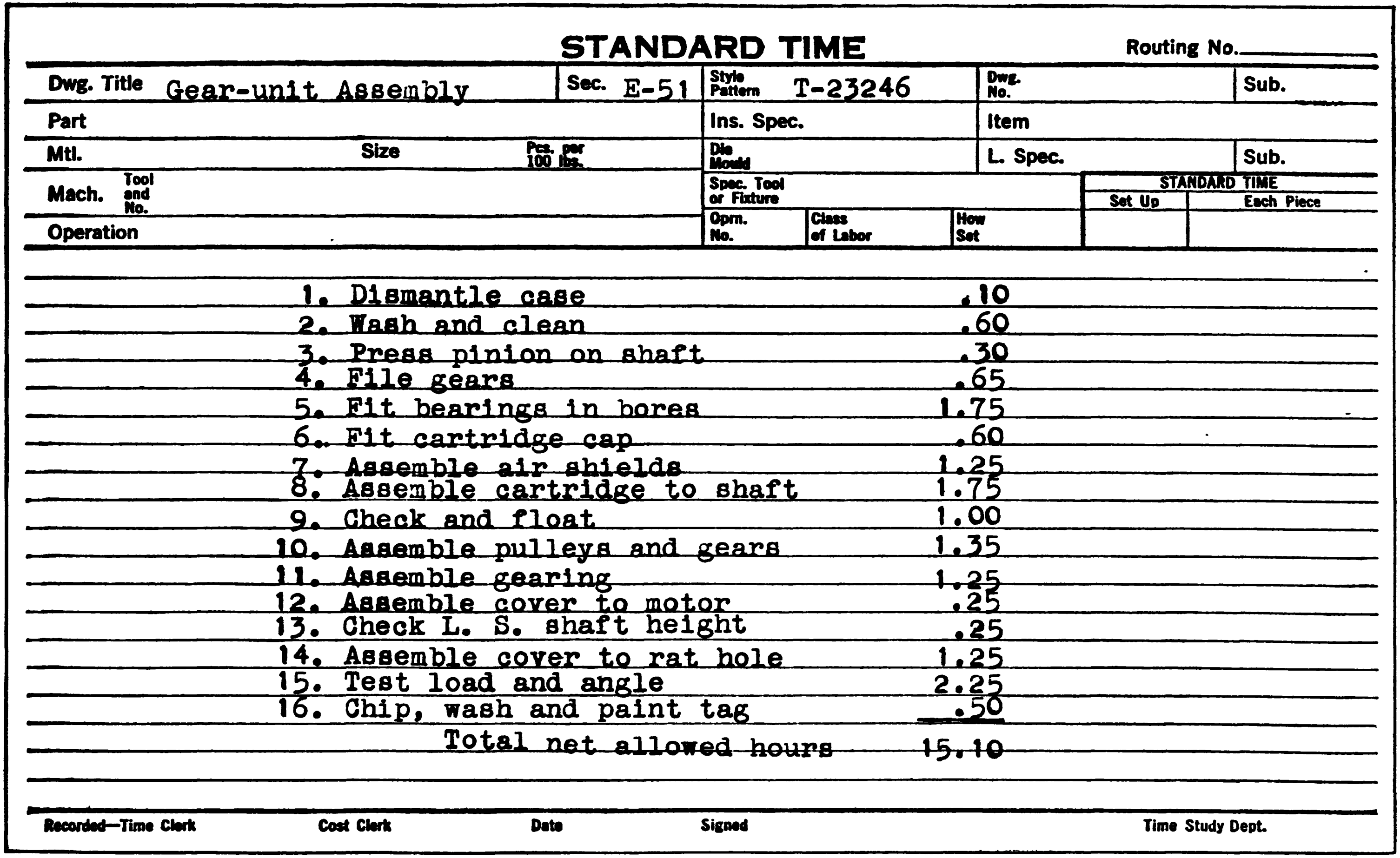


FIG. 62. *Layout design tailored to suit.* When all underlying factors of a layout project are supported by facts, the layout design, together with the material-handling methods, can be tailored to fit the problem. Suitable racks were provided in this case to permit the handling of the stators in "unit loads."

4. When? Manufacturing program and cycle.
5. How many? Quantity to be made and rate of production.

The present chapter deals entirely with questions 1 and 5. The other questions are analyzed in subsequent chapters.



STANDARD TIME Routing No.______

Dwg. Title Gear-unit Assembly | Sec. E-51 | Style Pattern T-23246 | Dwg. No. | Sub.

Part | Ins. Spec. | Item

Mtl. | Size | Pcs. per 100 lbs. | Die Mould | L. Spec. | Sub.

Mach. Tool and No. | Spec. Tool or Fixture | STANDARD TIME: Set Up | Each Piece

Operation | Oprn. No. | Class of Labor | How Set

1. Dismantle case	.10
2. Wash and clean	.60
3. Press pinion on shaft	.30
4. File gears	.65
5. Fit bearings in bores	1.75
6. Fit cartridge cap	.60
7. Assemble air shields	1.25
8. Assemble cartridge to shaft	1.75
9. Check and float	1.00
10. Assemble pulleys and gears	1.35
11. Assemble gearing	1.25
12. Assemble cover to motor	.25
13. Check L. S. shaft height	.25
14. Assemble cover to rat hole	1.25
15. Test load and angle	2.25
16. Chip, wash and paint tag	.50
Total net allowed hours	15.10

Recorded—Time Clerk | Cost Clerk | Date | Signed | Time Study Dept.

FIG. 63. *Operation routing.* Net allowed hours of cycle time per unit of product, obtained from the operation layout file or from shop order masters and prepared by the time-study department.

2. DETERMINING THE PROJECTED OUTPUT CAPACITY

Factors Affecting the Manufacture of the Product

Before attempting to determine the quantity to be made and the rate of production, careful consideration has to be given to the nature of the product itself, its design, its variety of styles and sizes, its dimensional accuracy and finish requirements, the manufacturing methods that may be used, the standardization possibilities of the product, the life of the product design, and other tangible and intangible factors affecting the very manufacture of the product. Any one, or a combination, of these factors may exert a marked influence on the plant layout design. For example, a product design involving grey-iron castings, as against a design made from zinc die casting, may render a thoroughly efficient plant layout completely obsolete if competition has sold the market on zinc die castings.

Since the quantities of the product to be manufactured basically determine the output capacity of the plant layout, every factor influencing these quantities has to be analyzed factually if the layout is to be designed accurately. A mere opinion that "we can sell a million a year" is plainly not the starting point of a plant layout project.

Forms Used for Determining Output Capacity Requirements

The data requirements vary greatly from project to project. For this reason, no fixed pattern or flow of data can be established as a standard. Several types of forms are used at various times and in various sequence on different projects. The sequence of the 10 representative forms enumerated below in no way represents a customary sequence. Only on rare occasions are all these forms used, and perhaps in no two cases are they used in the same order.

PLANT LAYOUT FORMS

(Specimen set of 10 representative office forms used for determining capacity requirements for a plant layout project.)

1. **Product load analysis** (Figure 64). To list the "proposed annual activity" of each finished product to be made in the new layout. This yearly production quantity forms the basis for determining the monthly activity of component parts on the form for **component part analysis** (Figure 65).
2. **Component part analysis** (Figure 65). One form for each finished product listed on the form on **product load analysis** (Figure 64). Breakdown of a finished product into its component parts. The monthly activity of these component parts forms the basis for preparing the form on **manufacturing layout data** (Figure 68).
3. **Manufacturing layout data** (Figure 68). One form for each component part listed on the form on **component part analysis** (Figure 65). Process routing of a component part into its sequence of machine operations. The monthly load of these separate operations forms the basis for the final selection of the most suitable manufacturing methods and machines and for the compilation of the form on **machine load data** (Figure 66) and the form on **manufacturing layout and estimate** (Figure 70).
4. **Machine load data** (Figure 66). One form for each machine appearing on the forms on **manufacturing layout data** (Figure 68). Recapitulation of the monthly load of

all operations routed to a machine. The total monthly load for a type of machine forms the basis for determining the number of this type of machine required for the plant layout project.

5. **Machine-tool layout information** (Figure 32). One form for each machine tool involved in the particular plant layout project. This two-sided card is prepared for proposed, as well as for existing, types of machine tools. When filed by tool tag number or plant location, these cards lend themselves to quick reference. This file also obviates the necessity of making physical checks on the premises whenever the need arises for basic data on operating units. This information is summarized on the form on **equipment and facilities requirements** (Figure 33) for specific layouts.
6. **Operation Analysis** (Figure 57). One form for each principal component part listed on the form on **component part analysis** (Figure 65). The flow and sequence of all operations (OP), transports (T), temporary storages (TS), inspections (INS), permanent storages (PS), and foreign elements (F) are given for the part. For each of these operation elements, the analysis also shows the time and distance between each element. The worksheet on which the statistics are gathered for drawing up this operation analysis is illustrated on the form **work sheet for operation and flow process charts** (Figure 75).
7. **Manufacturing layout and estimate** (Figure 70). One or more forms for each product. The component parts of the product are listed separately on this form. Each operation for a component part is shown on an individual line across the entire form. The information for each operation is taken from the form on **manufacturing layout data** (Figure 68) on which preliminary estimates were made. The recapitulation made on the form in Figure 70 is for the purpose of evaluating the operating cost and investment cost of the particular manufacturing method selected.
8. **Plant layout comparison sheet** (Figure 67). One or more forms for each finished product. The component parts of the product are listed separately on this form. For each part only one line is used to describe the manufacturing method. On that one line are shown the total time values and costs for all operations as summarized on the form on **manufacturing layout and estimate** (Figure 70). For each part listed, the time allowance and distance traveled under the new method are compared with those under the existing method or with those of alternate proposed plans. This comparison provides a measure of the results obtainable from the changeover.
9. **Equipment and facilities requirements** (Figure 33). One line for each unit of machinery and equipment. This information is summarized from the detail form on **machine-tool layout information** (Figure 32). The form of Figure 33 eliminates the need of cluttering up plant layout drawings with numerous notations on machinery and equipment. This form supports the plant layout drawing. It serves the multifold purpose of summary sheet, bill of material, and simplified specification sheet on machinery and equipment.
10. **Work-station layout** (Figures 56 and 78). Prepared as required, for single units of existing machinery and equipment. This layout allows for the travel area of all moving parts of each machine and for auxiliary equipment used at the work station. Work-station layouts are also prepared for all additional machinery and equipment required for the projected output.

Number of Forms Used

On some projects, particularly of a simple revision nature, it is entirely possible that none of these forms may apply, and that special ones may have to be designed. By and large, however, the average project calls for most of these 10 forms. Through the use of such forms, the results sought in a plant layout are achieved more expeditiously and dependably than otherwise.

This collection of forms (available from the authors) provides virtually all the essential data necessary to prepare layout plans for any type or size of project, from a single work station up to and including a complete new plant. The purpose of illustrating these forms is to display the type of information that will enable plant layout engineers to revise, develop, and design plant layouts in the most effective manner. In the legends of the figures referred to above, each of these forms is described as it applies to the development of a plant layout project.

3. BASIC FACTORS UNDERLYING THE OUTPUT CAPACITY DATA

From a broad viewpoint, the basic factors to be carefully scrutinized in compiling the output capacity of a plant layout project, whether for a revised layout or for a new undertaking, are listed as follows in the order of their importance: (1) market research; (2) economic quantities to be produced; (3) obsolescence of the product design; (4) cost of production; (5) quality control; (6) capital investment for plant facilities.

1. Market Research

At the root of all new projects, particularly when new product designs are the motivating factor giving rise to the need for a plant layout, is the estimate of the quantities required. To obtain a reliable estimate of sales volume, a careful survey should be made by the sales department or by an outside market research agency. This survey should cover foreign as well as domestic markets and should indicate the extent of the probable sales volume that the company may reasonably expect to realize for the products to be made in the new layout. The current price structure and the trend of prices projected over at least three years are also important indications to be supplied in the sales survey.

The effect of the price level on the sales demands for a product greatly influences the quantity volume to be manufactured. For example, if a product has been previously marketed at a sales price of $100 a unit, the market demand may conceivably be tripled when the sales price is reduced to $75. An analysis of production costs may reveal that with a tripled volume the net profits may be larger when the product sells at the lower figure.

In designing plant layouts, provision is often made for gradual increases in output volume up to an optimum operating capacity. With the flexibility injected by this type of planning, especially for new products, markets can be expanded, prices reduced, and plant operations kept in balance over a long period, at the same time reflecting favorable results on the profit statement. On the other hand, some products may have an inflexible or limited market, regardless of the price level. Under such circumstances, the output capacity should be based on the limited volume attainable, provided the quantity is sufficient to yield a satisfactory profit.

2. Economic Quantities to Be Produced

From the quantity requirements estimated in the market survey, the following three relationships must be established for the projected layout:

a. The manufacturing cycle for the product.
b. The inventories of component parts to be kept in stock.
c. The minimum quantity of each part which may be manufactured economically in a single lot.

No standard formula exists for correlating these three interdependent production factors, inasmuch as each product has its own set of relationships. In studying these relationships for a given product, consideration should be given to the following cost elements:

a. Setup cost for each operation on a component part.
b. Carrying charges on stocks of component parts and completed assemblies.
c. Cost of handling and storing component parts and completed assemblies.
d. The "lag" periods between component parts and subassemblies in the manufacturing cycle for the finished product.
e. The scheduled shipments of the product by months or weeks.

Excess inventories and setup costs often throw an otherwise profitable line of products into a ruinous operating loss.

3. Obsolescence of the Product Design

With the rapid progress made each year in materials, product designs, and finishes, the potential obsolescence of a product is a matter requiring close examination in planning a layout. The economic advantages of mass production can quickly turn into a heavy cost penalty when large inventories of obsolete products are tied up in stockrooms and warehouses. The probable life of a product design is therefore a main factor to be ascertained at the outset. Only after this has been properly ascertained can attention be drawn to the rate of production needed to meet market requirements, and to the resulting cost of production.

4. Cost of Production

The old practice of letting cost determine price has generally been supplanted by the more prevalent practice of starting with an estimate of the market price for the product and then finding a way of producing the goods at a cost that will leave a fair margin of profit. In the quest for such a cost, the quantities to be manufactured largely determine the most economical type of method or process to be employed, as well as the equipment investment required.

The influence of manufacturing quantities on the selection of methods and equipment may be illustrated with a simple case in which the quantity is increased from a sum of 10 units up to one of 100,000 units. The operation consists of drilling four holes into a piece part. So long as the quantity remains at 10 units, the part can be laid out by hand and the drilling can be done on an ordinary drill press costing $200. When the quantity increases to 1,000 pieces a jig is justified, and the investment rises to $250. If the quantity reaches 100,000 pieces, however, a metal-stamping operation might be more economical, even though this equipment may involve an investment of $2,500. As the equipment investment is increased successively from $200 to $2,500, the unit cost per piece keeps coming down. Thus, the resulting unit cost of production has a definite influence in the selection of the equipment for the proposed layout.

5. Quality Control

Many persons think of quality control only in terms of dimensional accuracy in the product, adherence to engineering specifications, and customer acceptance. From the standpoint of manufacturing quantities, the amount of work in process has a direct influence on the quality of the product wholly aside from the general conception of quality control. For example, quality deterioration in the product increases in proportion to the amount of handling and storing which the product undergoes during the course of the manufacturing process. Significant losses in worked material can easily occur from handling and storage. This hazard must be fully considered in designing a plant layout.

6. Capital Investment for Plant Facilities

The quantities to be manufactured also have a direct bearing on the amount of investment justifiable for plant facilities. Under factor 4, **cost of production,** a simple illustration was given of the way in which the size of manufacturing quantities largely determines the method and tooling to be used. These quantities likewise influence the selection of equipment and the amount of capital investment justified for a project. Small lots may usually be handled on standard machine tools or other production equipment. When large volumes of manufacturing justify the use of single-purpose machinery and equipment, the capital investment involved rises considerably. Here again, the final criterion on the amount of capital to invest in a project is supplied through an analysis of the production cost per unit of product.

4. ANALYSIS OF PERFORMANCE ON THE EXISTING LAYOUT

Gauging the Performance on the Existing Layout

The first step in the statistical analysis of any layout project is to ascertain the present performance on the existing layout. This forms the basis from which an improvement may be developed. When the layout has been completely designed, it will be necessary to measure the improvement it offers and to weigh this improvement against the cost of the installation. Furthermore, before seeking to make improvements, it is necessary to know in advance what the present conditions are like factually. Present performance is the actual gauge of present conditions, and therefore marks the starting point in the analysis.

When the contemplated project is entirely new and has no parallel operations in existing activities in the plant, it is then necessary to start from scratch without the guidance of actual operation statistics, and all figures must be estimated.

Whether all the figures are estimated or whether some are obtainable from current operations, the logic followed is the same. For the sake of illustration, then, let us consider an actual situation in a plant department where some of the production data needed for the layout project are available from current production.

Illustration of Actual Performance in a Plant Department

Present output is obtained from the production department. Present performance marks the starting point in the analysis preparatory to planning the output for a new layout project. The labor hours and number of men involved in the present output are furnished by the accounting department. These statistics are

TABLE 2. ACTUAL PERFORMANCE ON EXISTING LAYOUT

DEPARTMENT: GEAR-UNIT ASSEMBLY

Description of Data	Last 12 Months (1)	Average per Month (2)	Highest Month (3)	Latest Month (4)
OUTPUT				
Number of units assembled	6,543	545	659	455
STANDARD LABOR HOURS ALLOWED				
Net allowed hours	69,520	5,793	6,861	5,413
Setup hours	1,777	148	148	79
Extra allowance hours	16,767	1,397	1,570	1,383
Expense hours	6,177	515	393	497
Non-saleable product	11,716	976	935	442
Miscellaneous hours	212	18	29	26
Total allowed hours	106,169	8,847	9,936	7,840
ELAPSED HOURS				
Total elapsed hours	88,259	7,355	8,336	5,916
EFFICIENCY				
Percent efficiency	120%	120%	119%	133%
AVERAGE HOURS PER UNIT ASSEMBLED				
Net allowed hours	16.2	16.2	15.1	17.2
Elapsed hours	13.5	13.5	12.6	13.0
NUMBER OF WORKERS				
Assembly crew, 1st shift	24	24	23	19
Assembly crew, 2nd shift	18	18	18	16
Operator, 3rd shift	1	1	1	1
Foreman	1	1	1	1
Inspectors	3	3	3	3
Lapping machine operators	2	2	2	2
General laborers	2	2	2	2
Packer	1	1	1	1
Time-study man	1	1	1	1
Shop clerks	4	4	4	4
Total force in department	57	57	56	50

shown in Table 2. Each column represents a significant period of time selected as a basis for measuring existing activity as follows:

Column 1: **Last 12 months.** Since all projects are ultimately evaluated in terms of a year's business, this column forms the basis of the analysis.

Column 2: **Average per month.** This is nothing more than column 1 divided by 12 to arrive at an average monthly output for the purpose of expressing the statistics in the language of the production department, namely, in monthly loads.

Column 3: **Highest month.** Since this particular month reflects the highest output of any month in the 12-month period, it is shown here as a basis for comparison with the output that will be planned on the new layout.

Column 4: **Latest month.** This column supplies statistics for the most recent month. The output shown in this column will be broken down into specific detail by types of gear units, subassemblies, piece parts, individual operations, time values, etc., in the subsequent steps of the statistical analysis.

Analyzing the Output Figures

The output figures, in terms of units of gear units assembled, show that the average month for the 12-month period amounts to 545 units. During the high month of that year, 659 units were produced. This particular month, however, had 5 accounting weeks in it. Reducing the 5-week figure of 659 units to the basis of a 4⅓-week month, this output becomes 571, or but 5 percent above the average month. On the other hand, the output of but 455 units for the latest month covers only 4 accounting weeks. Adjusting this figure for 4⅓ weeks, this output becomes 493 units, or but 10 percent below that of the average month.

Taking into consideration the status of work in process at the start and close of the high month and of the latest month, the figures indicate that the volume of output of these two particular months was practically no different from the 545 units obtained during the average month. It is therefore safe to proceed with our analysis of the output during the latest month as being representative of the entire year, without fear of having overlooked some "bogey" month which might have served as a better criterion. It is well to keep such facts in mind throughout the analysis so as not to use superficial "spot" months too literally as a gauge of present capacity or activity.

5. BREAKDOWN OF TOTAL OUTPUT INTO TYPES OF PRODUCTS

Developing Number of Labor Hours per Unit of Product

We saw in Table 2 that 455 gear units were assembled in the latest month on record, and that, after considering the number of accounting weeks included in this month and allowing for the status of work in process at the beginning and end of the month, this figure was representative of present monthly capacity for an entire year. Whether all types of gear units incur the same number of labor

TABLE 3. LATEST MONTH'S OUTPUT BY TYPES OF PRODUCT

GEAR UNITS		UNITS PRODUCED IN LATEST MONTH	NET ALLOWED HOURS OF RUNNING TIME *			
			Actual on Present Layout		Estimated for New Layout	
Type of Unit	Size of Case		Total Hours	Per Unit	Per Unit	Percent Decrease
(1)	(2)	(3)	(4)	(5)	(6)	(7)
NEW-TYPE UNITS						
T	22248	1	13	12.90	10.71	17%
T	22842	7	93	13.30	11.03	17
T	23246	113	1,707	15.10	12.53	16
T	23641	10	254	25.43	21.11	17
T	25050	1	29	29.24	24.27	17
WE	22841	2	33	16.45	13.55	18
WE	23263	20	352	17.58	14.58	17
B	22042	1	12	12.00	12.00	—
F	23265	1	18	18.00	18.00	—
Total new-type units		156	2,511	16.09	13.38	17
PRESENT STANDARD UNITS						
E	12045	56	218	3.90	3.40	13
E	12241	1	4	4.35	3.50	20
E	12843	3	17	5.62	4.35	23
E	13268	4	26	6.49	4.56	28
GF	12048	12	47	3.90	3.53	10
GF	12246	36	164	4.60	3.94	14
GF	12840	30	167	5.57	4.59	18
GF	13269	13	83	6.41	5.67	12
GF	12547	6	28	4.64	3.99	16
GF	13641	2	14	7.05	5.92	16
U	12043	12	113	9.45	8.02	15
U	12240	5	60	12.02	10.08	16
U	12542	1	12	12.16	10.15	17
T	12244	10	47	4.70	3.89	17
T	12847	8	45	5.60	4.41	21
T	13246	6	41	6.47	5.13	21
T	13640	3	23	7.62	5.60	27
T	12048	1	4	3.98	3.60	1
T	12541	4	19	4.85	3.98	18
T	14042	2	17	8.45	6.38	24
T	14445	3	29	9.57	7.99	16
WT	12543	6	67	11.25	9.25	18
WT	12846	3	39	12.85	10.80	16
WT	13268	38	472	12.42	10.70	14
NX	11259	4	22	5.53	4.50	19
D	12844	30	300	9.99	8.29	17
Total standard units		299	2,078	6.95	5.86	16
GRAND TOTAL UNITS						
Units completed		455	4,589	10.08	8.44	16
Work in process			824	1.81	1.52	16
Total net allowed hours			5,413	11.89	9.96	16%

* **Each type of product** incurs a specific number of labor hours per unit. Ways of improving the work being done on present types of products, through a better layout, spring from these basic figures.

hours per unit is our next concern in the analysis. This is developed in Table 3 in the columns described below:

Columns 1 and 2: **Gear-unit types and sizes.**

Column 3: **Units produced in latest month.** The total of 455 units appearing at the foot of the table is made up of 156 new-type units and 299 present standard units. The number of each type of unit varies from a minimum of 1 for each of seven types up to 113 for Type T-23246 shown on the third line. The irregular weighting which these individual quantities carry into the average net allowed hours (10.08 in column 5) for the entire list exerts a marked influence on the significance and application made of this over-all average.

Columns 4 and 5: **Actual net allowed hours on present layout.** This information is obtained from the operation layout files in the time-study department (see specimen form in Figure 63). It will be noted that although the average for all 455 units amounts to 10.08 net allowed hours per completed unit, the new-type units average 16.09 hours each, whereas the present standard units average but 6.95 hours apiece. Furthermore, the time allowance per unit varies all the way from a minimum of 3.90 hours to a maximum of 29.24. The latter takes more than 7 times as many hours as the former, and both types are the most active on the list.

Selection of the Representative Product Unit

In planning a layout for this line of gear units, neither the 3.90-hour unit nor the 29.24-hour unit can properly be taken as a representative product unit for developing the output capacity in the new layout. A more representative basis is the average number of hours for all 455 units, or 10.08 hours per unit.

Thus far, our figures on time allowed have been supplied by the time-study department for each type of unit. The extension of these unit rates by the number of units produced results in a total of 4,589 net allowed hours for the month. The payroll, however, shows 5,413 hours, or 824 more hours due to time paid for work in process, which time is not included in the production figures until the units have been completed.

6. PRELIMINARY LAYOUT OF POSSIBLE IMPROVEMENTS

Exploring Improvement Possibilities in Present Layout

Before proceeding with planning a layout for the new line of gear units, we must first determine the ways in which a new layout could improve the assembly work now being done on the present types of gear units. This is done through the medium of designing work-station layouts (see Chapter X) for the existing types of units, and preparing a preliminary floor layout of these work stations to study the flow of production that would be the most suitable for these work stations. In the case at hand, the preliminary layout brought out three decisive points on this score, namely:

1. Changing from unit assembly to progressive assembly eliminates setup time.
2. Matching parts in a dispatch station reduces extra allowance hours by 50 percent.
3. Increasing the number of inspection points reduces expense hours by 50 percent in repairing rejects.

The determination of these effects on the output for the latest month of production is shown in Table 3 as follows:

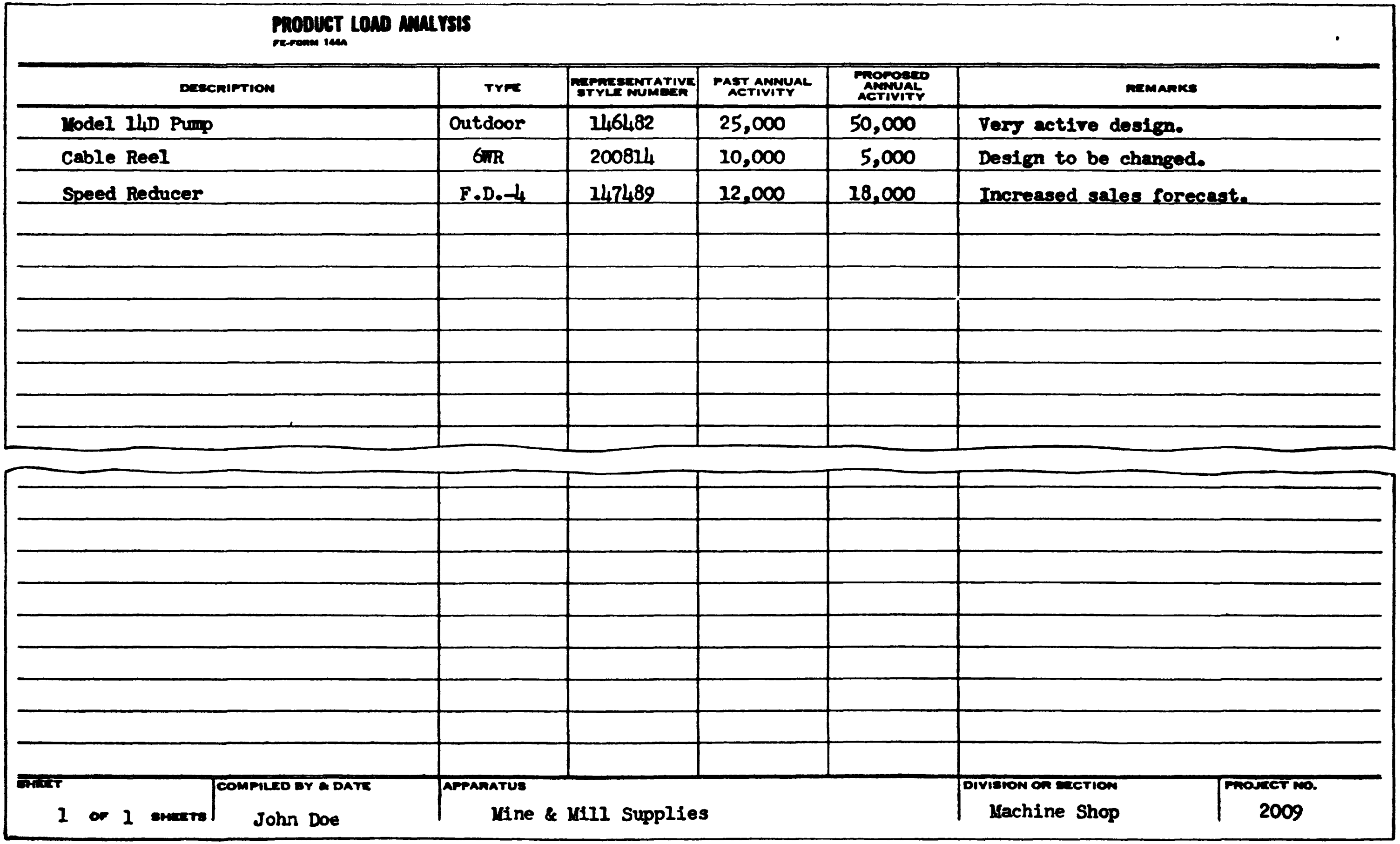
Column 6: **Estimated running time per unit on new layout.** These time allowances are secured from the time-study department and indicate the new time values that would be given each type of unit if assembled on the new layout.

Column 7: **Percent decrease in net allowed hours on new layout.** The hours saved per unit (Column 5 minus Column 6), divided by the present running time per unit (Column 5), reflect an over-all reduction of 16% (Column 7) in running time resulting from the new layout features.

What this saving means in terms of money for the volume of production over the last 12 months (see Table 2, Column 1), is summarized in Table 4.

TABLE 4. ANNUAL SAVING BY PRODUCING PRESENT OUTPUT ON NEW LAYOUT

DESCRIPTION OF STANDARD LABOR HOURS ALLOWED	COMPARISON OF HOURS FOR 455 UNITS PRODUCED IN LATEST MONTH				ESTIMATED SAVINGS IN HOURS ALLOWED ON 6,543 UNITS PRODUCED IN LAST 12 MONTHS	
	Actual Hours on Old Layout		Estimated Hours on New Layout			
	Total Hours	Hours per Unit	Hours per Unit	Percent Decrease	Actual Hours on Old Layout	Savings on New Layout
Net allowed hours	5,413	11.89	9.96	16%	69,520	11,123
Setup hours	79	.17		100	1,777	1,777
Extra allowance hours	1,383	3.04	1.52	50	16,767	8,383
Expense hours	497	1.09	.55	50	6,177	3,088
Non-saleable product	442	(This allowance unchanged)			11,716	
Miscellaneous hours	26				212	
Total allowed hours	7,840				106,169	24,371
Average wage rate						×$1.412
Annual saving in labor cost						$34,412

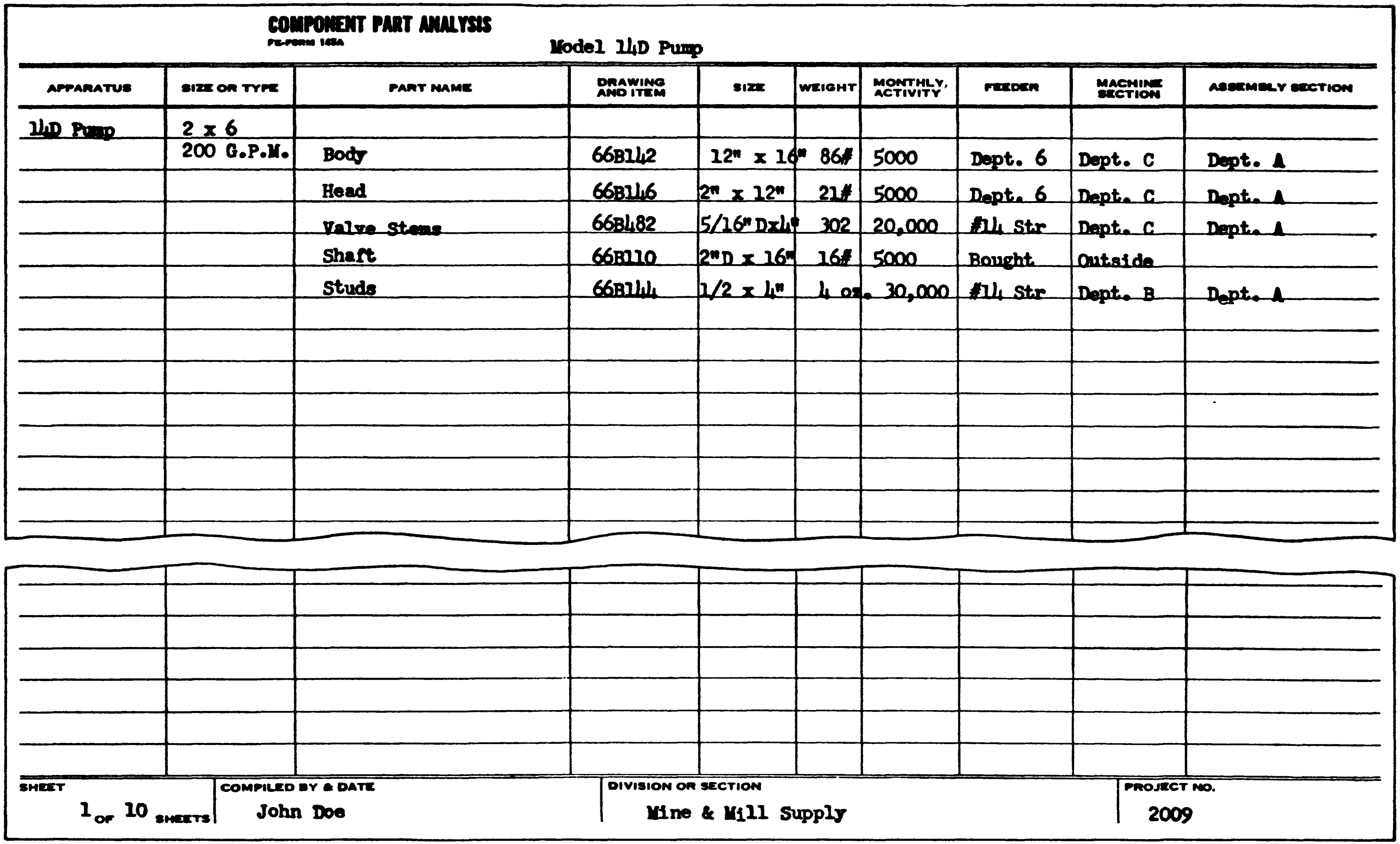


PRODUCT LOAD ANALYSIS
FE-FORM 144A

DESCRIPTION	TYPE	REPRESENTATIVE STYLE NUMBER	PAST ANNUAL ACTIVITY	PROPOSED ANNUAL ACTIVITY	REMARKS
Model 14D Pump	Outdoor	146482	25,000	50,000	Very active design.
Cable Reel	6WR	200814	10,000	5,000	Design to be changed.
Speed Reducer	F.D.-4	147489	12,000	18,000	Increased sales forecast.

SHEET	COMPILED BY & DATE	APPARATUS	DIVISION OR SECTION	PROJECT NO.
1 OF 1 SHEETS	John Doe	Mine & Mill Supplies	Machine Shop	2009

FIG. 64. *Yearly production quantity of each product* to be made forms the basis for determining the monthly activity of component parts on form for component part analysis (Figure 65).



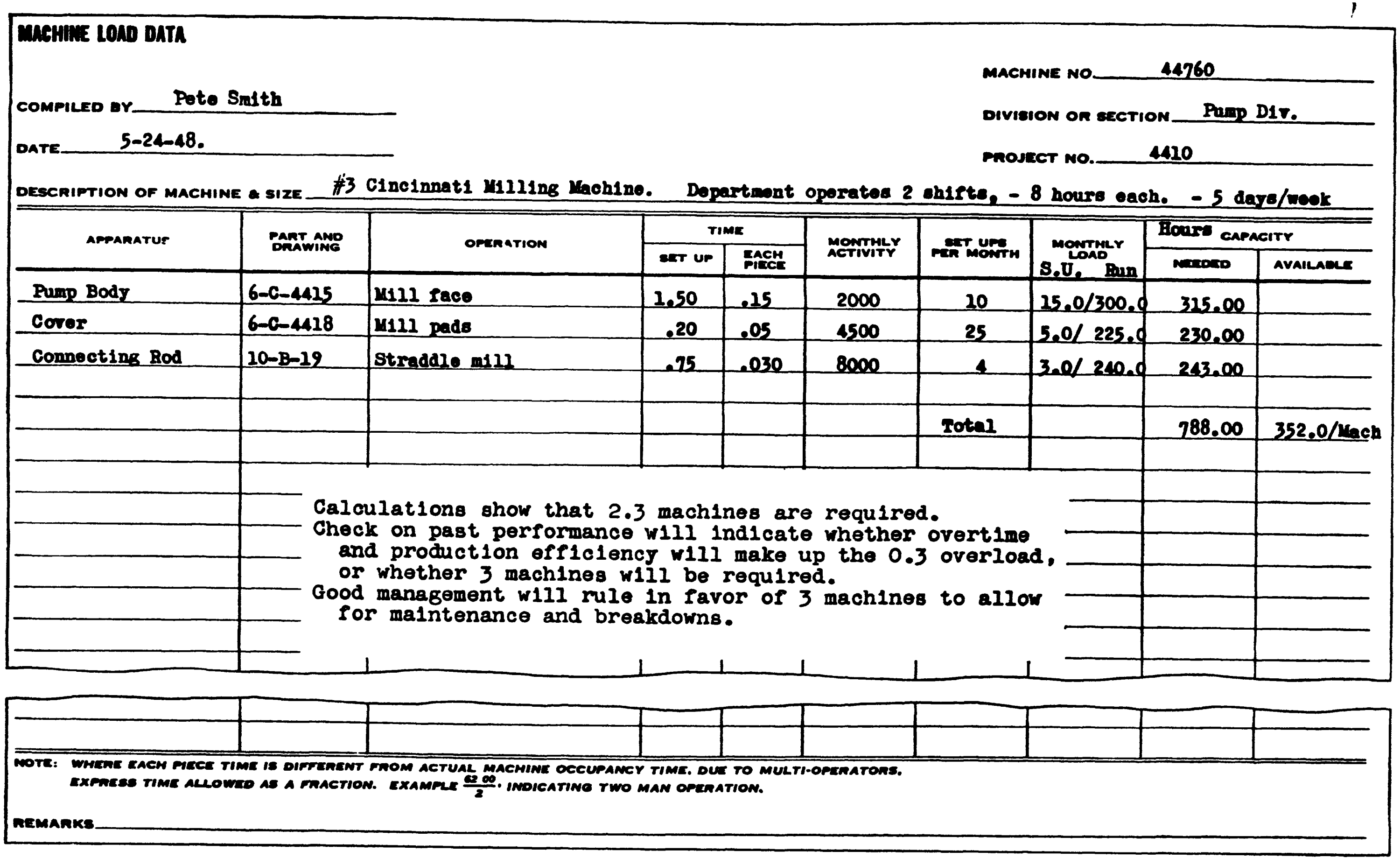
COMPONENT PART ANALYSIS
PE-FORM 145A

Model 14D Pump

APPARATUS	SIZE OR TYPE	PART NAME	DRAWING AND ITEM	SIZE	WEIGHT	MONTHLY ACTIVITY	FEEDER	MACHINE SECTION	ASSEMBLY SECTION
14D Pump	2 x 6								
	200 G.P.M.	Body	66B142	12" x 16"	86#	5000	Dept. 6	Dept. C	Dept. A
		Head	66B146	2" x 12"	21#	5000	Dept. 6	Dept. C	Dept. A
		Valve Stems	66B482	5/16"Dx4"	302	20,000	#14 Str	Dept. C	Dept. A
		Shaft	66B110	2"D x 16"	16#	5000	Bought	Outside	
		Studs	66B144	1/2 x 4"	4 oz.	30,000	#14 Str	Dept. B	Dept. A

SHEET	COMPILED BY & DATE	DIVISION OR SECTION	PROJECT NO.
1 OF 10 SHEETS	John Doe	Mine & Mill Supply	2009

FIG. 65. *Breakdown of a finished product* into its component parts forms the basis for preparing the form on manufacturing layout data (Figure 68).



MACHINE LOAD DATA

COMPILED BY Pete Smith

DATE 5-24-48.

MACHINE NO. 44760

DIVISION OR SECTION Pump Div.

PROJECT NO. 4410

DESCRIPTION OF MACHINE & SIZE #3 Cincinnati Milling Machine. Department operates 2 shifts, - 8 hours each. - 5 days/week

APPARATUS	PART AND DRAWING	OPERATION	TIME		MONTHLY ACTIVITY	SET UPS PER MONTH	MONTHLY LOAD	Hours CAPACITY	
			SET UP	EACH PIECE			S.U. Run	NEEDED	AVAILABLE
Pump Body	6-C-4415	Mill face	1.50	.15	2000	10	15.0/300.0	315.00	
Cover	6-C-4418	Mill pads	.20	.05	4500	25	5.0/ 225.0	230.00	
Connecting Rod	10-B-19	Straddle mill	.75	.030	8000	4	3.0/ 240.0	243.00	
						Total		788.00	352.0/Mach

Calculations show that 2.3 machines are required.
Check on past performance will indicate whether overtime and production efficiency will make up the 0.3 overload, or whether 3 machines will be required.
Good management will rule in favor of 3 machines to allow for maintenance and breakdowns.

NOTE: WHERE EACH PIECE TIME IS DIFFERENT FROM ACTUAL MACHINE OCCUPANCY TIME, DUE TO MULTI-OPERATORS, EXPRESS TIME ALLOWED AS A FRACTION. EXAMPLE $\frac{62.00}{2}$, INDICATING TWO MAN OPERATION.

REMARKS

FIG. 66. *Monthly load for each type of machine* forms the basis for determining the number of machines required for the plant layout project.

Annual saving of $34,412 is obtained in labor cost by producing present output of existing units on new layout.

The cost of installing the new layout was estimated at $24,100, thus permitting the project to pay for itself during the first 8 months of operation after installation.

Product Load Analysis

In situations where the new project calls for new products and operations for which actual performance statistics are not available, the load analysis would begin with a Product Load Analysis, illustrated in Figure 64, showing the annual output of each type and size of product to be manufactured on the new layout. The yearly activity shown on this form for each product forms the basis for determining the monthly activity of the component parts entering into the product. This form would then be summarized by individual products, as in Table 3, leaving out columns 4 and 5 concerning present layout, and listing the forecasted production quantities in column 3 of the same listing.

Component Part Analysis

The next form used for compiling load data for a new project is the component part analysis illustrated in Figure 65. One of these forms is prepared for each product. This form breaks down the completed products from Figure 64 into their component parts.

The monthly activity of these component parts forms the basis for making the operation analysis on the form entitled "Manufacturing Layout and Estimate," illustrated in Figure 70. The component part analysis is used for constructing flow charts of material handled between departments.

In compiling this component analysis, it is necessary to dissect the completed product into the smallest piece part to be manufactured. These parts must then be further analyzed on the form in Figure 70 to determine material requirements, operations required, and routing of the operations. From the operations compiled on the form in Figure 70, the machine load data is recapitulated on the form in Figure 66.

7. THE MANUFACTURING PROGRAM AND PLANT CAPACITY

The Sales Forecast by Individual Products

A manufacturing program based on a sales forecast is usually expressed in lump quantities of products for a year, or for six-month periods. To be of value in planning a layout, the manufacturing program must be stated in terms of individual types and sizes of each product, and the yearly quantities subdivided into months so as to show the variations in requirements from month to month. These monthly production quantities by individual types and sizes of products may then be broken down into component parts, using for this purpose a form similar to the one illustrated in Figure 64.

Throughout the component analysis a distinction should be made between parts to be manufactured in the plant and parts that could be bought outside more economically. It should be borne in mind that the components that set up limiting factors of capacity in the new layout are those that are to be manufactured in the plant, and not those purchased outside.

Stock Orders and Job-Shop Manufacturing

In determining output requirements, it is also necessary to distinguish between stock orders and custom (or special-job) orders. When stock orders prevail in a new project, custom orders are scheduled to fit into the surplus machine capacity not assigned to stock orders on machine load charts. In this event, stock orders receive preference in scheduling production, and custom orders are subjected to delays in delivery. But if custom orders are in the majority they take precedence in machine loading, whereas stock orders are scheduled to the left-over capacities in the machines.

This method of scheduling leaves an uncertainty in the maintenance of adequate stocks on hand. Usually, however, with a proper exercise of judgment, occasional interruptions at convenient times will permit a switch from stock orders to custom orders, or vice versa, without disrupting operations. In determining output capacity needed, however, due provision has to be made for the coexistence of these two types of orders.

The Parasitic Nature of Small Orders

The acceptance of special orders for non-standard products often wrecks the best-planned production schedules and the best-designed plant layouts. The excessive setup cost and resulting machine delays occasioned by special orders is not often realized. The presence of special orders in some plants definitely prevents such plants from being able to accept large orders for standard products. The parasitic nature of special products upon the standard line is clearly illustrated in the following actual experience related in *Industrial Standardization:*

> At one time, in this furniture factory, special orders were cultivated to such a point that the filling of these orders interfered seriously with the manufacture of the standard product. A separate factory was finally erected for the special work. This led to more accurate cost-accounting which proved that the company was losing money on special orders. When the attempt was made to raise the price of the special product to the point where the special factory would pay its own way, it was found that this could not be done because the customer then preferred the standard product. As a result, the business in specials was eliminated.*

Nearly every industry is confronted with the problem of supplying replacement parts to service the products in the hands of consumers. There is also a certain amount of shrinkage in production due to losses, breakage, defectives, etc. In determining production capacity, due allowance has to be made for these intangible factors. It is not uncommon in many industries to find from 5 to 20 percent of the total production of parts being diverted into these channels.

---

* *Ind. Standardization,* editorial, January, 1942.

Inventory Levels Considered for the Layout

Another factor of major significance in planning a manufacturing program for a new layout project is the matter of merchandise inventories covering raw material, work in process, and finished parts and assemblies. It is not generally recognized, outside of administrative and accounting circles, that a large part of the capital required to operate a manufacturing enterprise is tied up in inventories. Unless inventory levels are co-ordinated to the rate of output, they usually climb into unnecessary sizes which cause carrying charges (including taxation in some states) to cut deeply into operating profits.

A certain determinable inventory level must be maintained for each material item in a product. Such a level is based on the availability of raw materials. market fluctuations in material prices, the manufacturing cycle of the finished product, and seasonal demands for the product. Since the size of merchandise inventories is directly dependent upon the quantities to be manufactured as well as upon the rate of production. inventory requirements should be determined accurately in planning the plant layout project.

Seasonal Influence on Production Activities

In converting the manufacturing program into component parts, close attention must be given to the seasonal aspects of a year's program. In some industries, notably in food-canning and automotive plants, the bulk of a year's business is carried on entirely within a season extending over but a few months out of the twelve-month period. This means. for example, that while the annual output may be, say, 1,000,000 units, this entire volume may be produced over a period of perhaps only 4 months.

For such a plant, the capacity designed into the layout would be based on a production rate of 250,000 units a month rather than on a monthly output of one-twelfth of 1,000,000 units, namely, 83,333 units. In industries that must produce a variety of products on a seasonal basis, the planning of this production is a critical issue. For such plants, the actual capacity is planned at a much higher level than would be the case if the manufacturing program for the year could be distributed uniformly over 12 months.

CHAPTER IX

Analyzing, Balancing, and Routing the Operations

1. PRELIMINARY ANALYSIS OF THE PLANT LAYOUT PROJECT

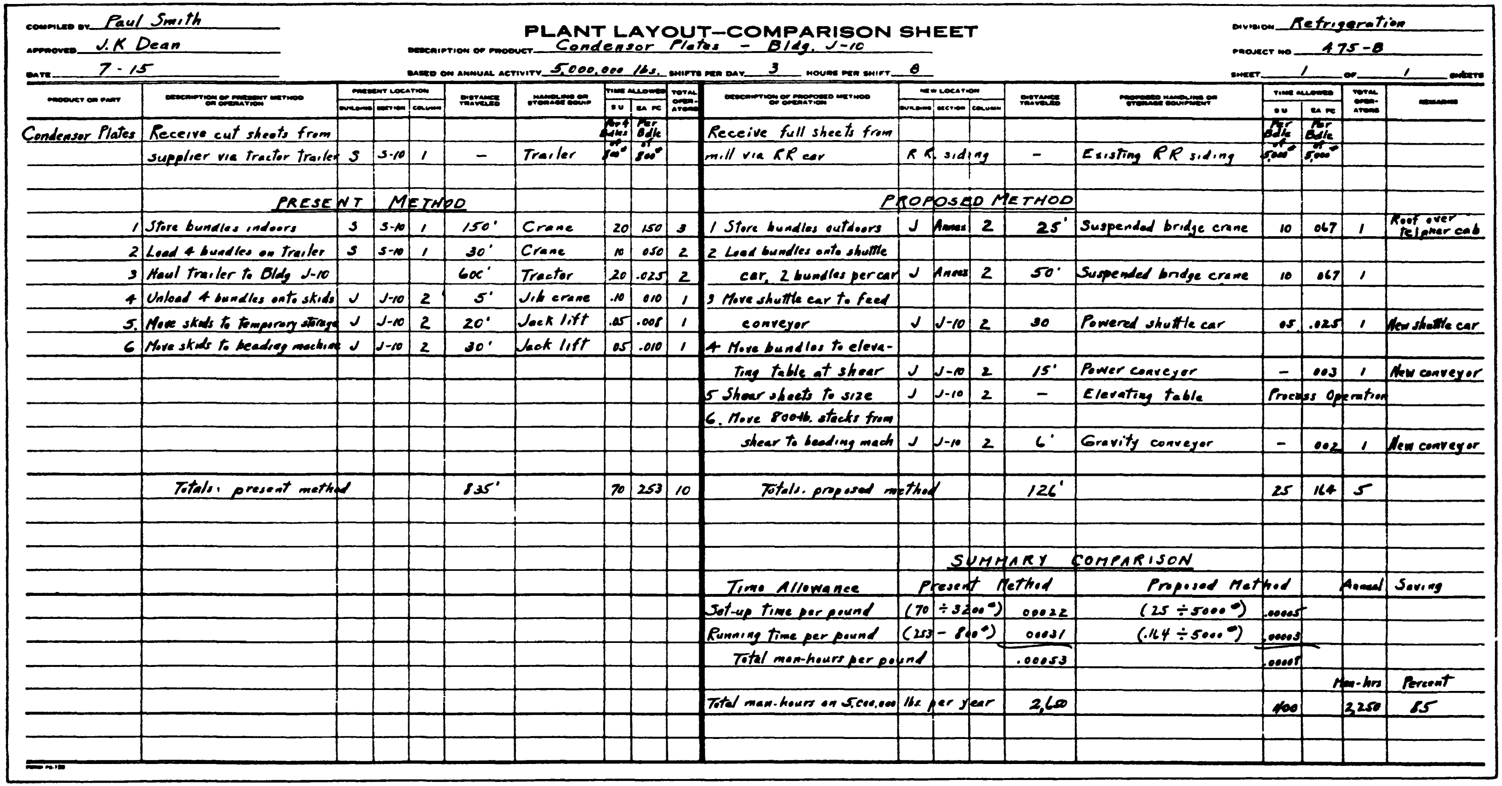
On the Threshold of Actual Plant Layout Design

In undertaking the practical application of principles at this point, the assumption is made that the following six preliminary steps described in Part 1 were duly executed before the decision was reached to proceed with the engineering work of designing an actual layout:

1. The **product** or products have been completely designed, tested, compared with competing products, and found ready for commercial production.
2. A comprehensive **market survey** has been made to determine the demand for the product, the portion of the market that the enterprise can reasonably expect to secure over a number of years, and the market price to be expected over the same number of years.
3. If a **new plant** is contemplated, the regional location has been selected and a survey made of the labor supply, transportation costs, power costs, and taxes in the locality selected.
4. The **quantity** of each product to be shipped, by months, over a number of years, has been determined from the projected sales requirements.
5. If an **existing plant** or existing facilities are to be utilized, the available machine capacity and floor space have been calculated thoroughly.
6. **Preliminary estimates** have been made from alternative plans to indicate the potential capital investment and net profit involved, and a sound justification has been obtained for proceeding with the actual development of the plant layout.

Preliminary Layout Plans from Rough Estimates

For run-of-the-mill plant layout projects not involving the construction of a new plant nor extensive alterations to existing buildings, many of these preliminary factors can be reliably estimated by experienced plant layout engineers without the necessity of compiling endless statistical information in support of preliminary alternative plans. It is only after one or more of these preliminary plans have been selected by management for actual development that the plant layout engineer undertakes to determine the number, type, and size of machinery,



PLANT LAYOUT—COMPARISON SHEET

COMPILED BY Paul Smith
APPROVED J.K Dean
DATE 7-15
DESCRIPTION OF PRODUCT Condensor Plates - Bldg. J-10
BASED ON ANNUAL ACTIVITY 5,000,000 lbs. SHIFTS PER DAY 3 HOURS PER SHIFT 8
DIVISION Refrigeration
PROJECT NO. 475-B
SHEET 1 OF 1 SHEETS

PRODUCT OR PART	DESCRIPTION OF PRESENT METHOD OR OPERATION	PRESENT LOCATION			DISTANCE TRAVELED	HANDLING OR STORAGE EQUIP	TIME ALLOWED		TOTAL OPERATORS	DESCRIPTION OF PROPOSED METHOD OF OPERATION	NEW LOCATION			DISTANCE TRAVELED	PROPOSED HANDLING OR STORAGE EQUIPMENT	TIME ALLOWED		TOTAL OPERATORS	REMARKS
		BUILDING	SECTION	COLUMN			S U	EA PC			BUILDING	SECTION	COLUMN			S U	EA PC		
Condensor Plates	Receive cut sheets from						Per 4 Bdles	Per Bdle		Receive full sheets from						Per Bdle	Per Bdle		
	supplier via tractor trailer	S	S-10	1	—	Trailer	of 800#	of 800#		mill via RR car	R R. siding			—	Existing RR siding	of 5,000#	of 5,000#		
	PRESENT METHOD									PROPOSED METHOD									
1	Store bundles indoors	S	S-10	1	150'	Crane	20	150	3	1 Store bundles outdoors	J	Annex	2	25'	Suspended bridge crane	10	067	1	Roof over telpher cab
2	Load 4 bundles on trailer	S	S-10	1	30'	Crane	10	050	2	2 Load bundles onto shuttle									
3	Haul trailer to Bldg J-10				600'	Tractor	.20	.025	2	car, 2 bundles per car	J	Annex	2	50'	Suspended bridge crane	10	067	1	
4	Unload 4 bundles onto skids	J	J-10	2	5'	Jib crane	.10	010	1	3 Move shuttle car to feed									
5.	Move skids to temporary storage	J	J-10	2	20'	Jack lift	.05	.008	1	conveyor	J	J-10	2	30	Powered shuttle car	05	.025	1	New shuttle car
6	Move skids to beading machine	J	J-10	2	30'	Jack lift	05	.010	1	4 Move bundles to eleva-									
										ting table at shear	J	J-10	2	15'	Power conveyor	—	003	1	New conveyor
										5 Shear sheets to size	J	J-10	2	—	Elevating table	Process Operation			
										6. Move 800lb. stacks from									
										shear to beading mach	J	J-10	2	6'	Gravity conveyor	—	002	1	New conveyor
	Totals: present method				835'		70	253	10	Totals. proposed method				126'		25	164	5	

SUMMARY COMPARISON

Time Allowance	Present Method		Proposed Method		Annual Saving	
Set-up time per pound	(70 ÷ 3200#)	00022	(25 ÷ 5000#)	.00005		
Running time per pound	(253 - 800#)	00031	(.164 ÷ 5000#)	.00003		
Total man-hours per pound		.00053		.00008		
					Man-hrs	Percent
Total man-hours on 5,000,000 lbs. per year		2,650		400	2,250	85

FIG. 67. *Difference in total operating cost.* Direct labor hours per year under the present plant layout are compared on this form with the corresponding hours under the proposed layout. As needed, these total hours are expressed in terms of direct labor cost, and the overhead cost is added to obtain the net difference in total manufacturing labor and expense.

material-handling equipment, work stations, areas, processing and service departments, etc., required for a selected plant layout project (see Figure 67).

2. OPERATION ANALYSIS OF MANUFACTURING METHODS

Fitting the Layout to the Operations

The foundation of all plant layout engineering rests upon the technical detail work involved in analyzing, timing, balancing, and routing the manufacturing operations necessary to fabricate, move, store, assemble, and co-ordinate the routing and scheduling of raw material, piece parts and subassemblies which enter into the finished products. From the calculations required in this detail emerges the pattern of the physical design of the layout. The accuracy of the plant layout can be no greater than the soundness and accuracy of the underlying detail data secured on manufacturing operations. To derive smooth, efficient operation from the project, the statistics and calculations of operations must mesh together like the gears in a gear train.

Once the quantities of each product to be manufactured have been determined, the first step is to analyze the contemplated processing operations. This may necessitate voluminous detail or only a negligible amount of paper work, depending on the magnitude or technical importance of the project. In either situation the work demands a high degree of accuracy. It is largely upon the accuracy of this basic detail that the following factors are ultimately gauged:

1. The amount of **capital investment** in machinery, equipment, and tooling. As indicated in later chapters, this investment in normal times is over twice as much as for the construction of the factory buildings. In abnormal times, this proportion runs higher. This relationship holds true, as a general rule, in all industries in this country.
2. The type and amount of **floor space** required.
3. The type and size of the **plant force.**
4. The **profit and loss** possibility from each alternative plan of plant layout.

Technical Knowledge of Processes

In compiling the detail data on operations, the plant layout engineer need not be thoroughly versed in the technical aspects of the manufacturing processes involved in the proposed layout. What he must know thoroughly, however, is the proper way of fitting these details together, qualitatively and quantitatively, into a harmonious assembly. The technical "know-how" of the processes is supplied by the product design engineers, process engineers, tool engineers, supervisory force, and management staff. In order to avoid confusion and misunderstanding in developing the project, it is of *extreme importance* to keep this distinction of responsibility in mind.

Compilation of Detail Data on Operations

As when compiling data on quantities to be produced, it is desirable to record as much detail on operations as possible for reference. Special forms, described in the following paragraphs, have been designed for this purpose to avoid the haphazard recording of such information in so-called "butcher books." These forms make it easier for all persons working on the project to interpret the information correctly. The forms also constitute a permanent record for reference.

The primary purpose in compiling detail information on operations is to provide a solid basis for establishing the proper manufacturing methods to be used in the project. In nearly every operation there is a choice of several alternative methods, but usually one best method. To determine this best method, a number of factors are analyzed and weighed carefully. In order to study these alternatives properly, each product is first dissected into its lowest element of component parts. Figuratively speaking, the product is broken down to the last nut and bolt it contains.

3. ESTIMATES OF MACHINE OPERATIONS AND LOADS

Two Stages of Estimating Operations

The compilation of data on machine operations is usually done in two stages, namely:

1. **Preliminary estimates** of machine operations and loads.
2. **Final studies** of operation time, factory cost, machine tools, floor space, and cost of machinery and equipment.

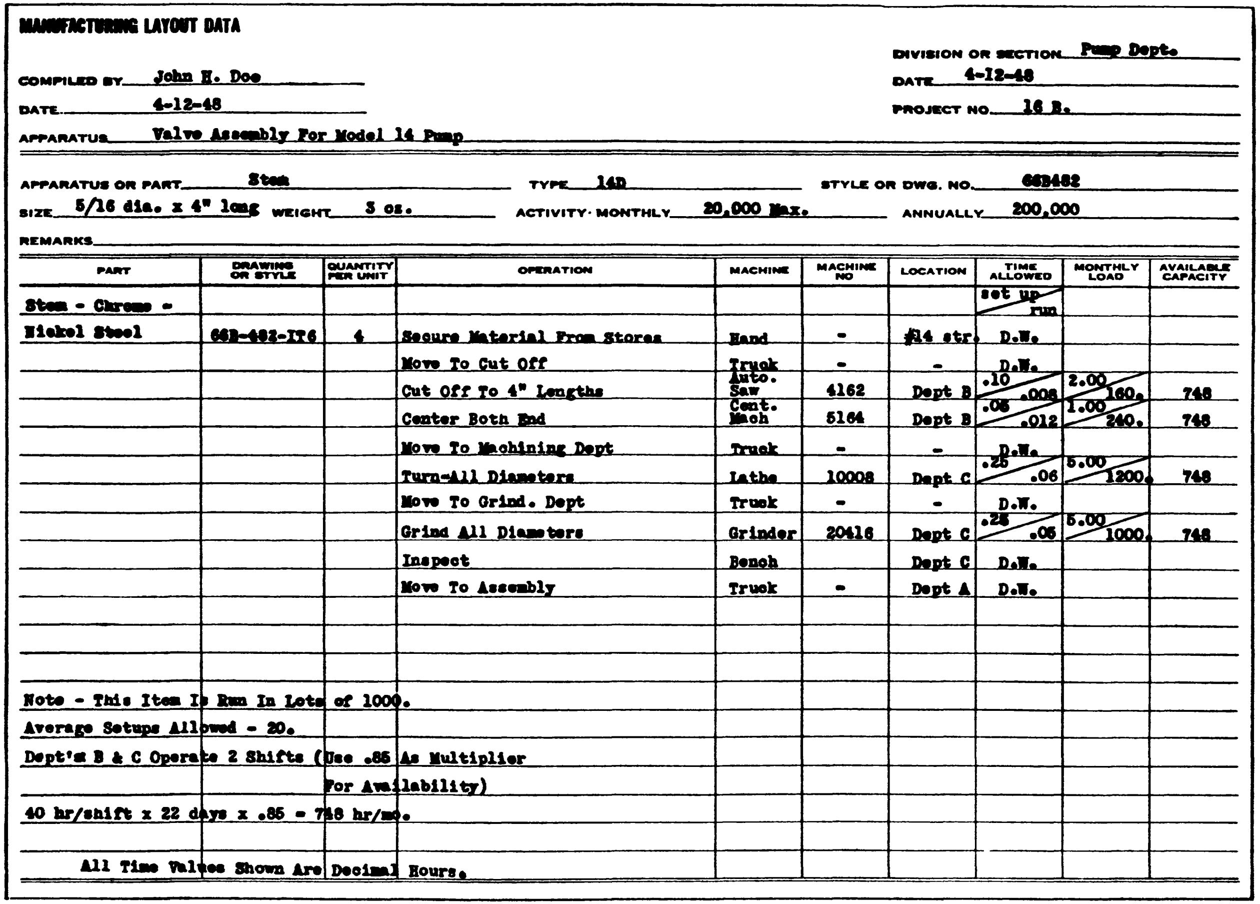
Preliminary Estimate of Machine Operations

In making preliminary estimates and tentative selections of machine operations, a form similar to the one in Figure 68, for compiling **manufacturing layout data,** is commonly used. The form is simple, practical, and yet comprehensive enough to supply the proper basis for the final selection of the particular manufacturing methods and machines that are the most suitable and economical for the project. A more elaborate form, Figure 70, described later, is used for the final studies in the second stage of the estimating.

One sheet of the manufacturing layout data form is used for each component part of the product to be manufactured in the new plant layout. In filling out this form, there should be no hesitancy to use several lines for an operation when necessary to avoid confusion. In compiling engineering data, paper is much cheaper than engineering time for digesting cramped information. For this reason, liberal space is allowed between parts or operations listed on the form so as to permit later insertions, revisions, and corrections.

Manufacturing Methods

The monthly and annual production requirements of the product or part analyzed on the form are shown in the heading of the sheet as taken from the production quantity determined from the estimated sales requirements previously described in Chapter IV. The parts of each product are listed individually on the form in the first column. The quantity of each part contained in a single unit of the product is shown in the third column. Then follows a column for



MANUFACTURING LAYOUT DATA

DIVISION OR SECTION Pump Dept.
COMPILED BY John H. Doe
DATE 4-12-48
DATE 4-12-48
PROJECT NO. 16 B.
APPARATUS Valve Assembly For Model 14 Pump

APPARATUS OR PART Stem
TYPE 14D
STYLE OR DWG. NO. 66B482
SIZE 5/16 dia. x 4" long
WEIGHT 3 oz.
ACTIVITY · MONTHLY 20,000 Max.
ANNUALLY 200,000
REMARKS

PART	DRAWING OR STYLE	QUANTITY PER UNIT	OPERATION	MACHINE	MACHINE NO	LOCATION	TIME ALLOWED	MONTHLY LOAD	AVAILABLE CAPACITY
Stem - Chrome -							set up / run		
Nickel Steel	66B-482-IT6	4	Secure Material From Stores	Hand	-	#14 str.	D.W.		
			Move To Cut Off	Truck	-	-	D.W.		
			Cut Off To 4" Lengths	Auto. Saw	4162	Dept B	.10 / .008	2.00 / 160.	748
			Center Both End	Cent. Mach	5164	Dept B	.05 / .012	1.00 / 240.	748
			Move To Machining Dept	Truck	-	-	D.W.		
			Turn-All Diameters	Lathe	10008	Dept C	.25 / .06	5.00 / 1200.	748
			Move To Grind. Dept	Truck	-	-	D.W.		
			Grind All Diameters	Grinder	20416	Dept C	.25 / .05	5.00 / 1000.	748
			Inspect	Bench		Dept C	D.W.		
			Move To Assembly	Truck	-	Dept A	D.W.		

Note - This Item Is Run In Lots of 1000.
Average Setups Allowed - 20.
Dept's B & C Operate 2 Shifts (Use .85 As Multiplier
For Availability)
40 hr/shift x 22 days x .85 = 748 hr/mo.
All Time Values Shown Are Decimal Hours.

FIG. 68. *Process routing of a component part* into its sequence of machine operations. The monthly load of these separate operations forms the basis for compiling *machine load data* (Figure 66) and *manufacturing layout and estimate* (Figure 70).

listing the *obvious* method of manufacturing. The final *best* method is not usually known at this early stage, but the most *obvious* method provides a good starting point, which may be improved upon later as the analysis develops along broader lines than are discernible at the moment.

In listing the operations for each component part, the following information is also shown for later use:

a. The source, destination, and distance of material movements.
b. The inspection points.
c. The storage pauses between processing operations.
d. The sequence of the separate processing operations.

The indispensability of this supplementary information will become apparent later in this chapter when the subject of flow diagrams is taken up.

Machine Loads

After a number of parts have been listed and the operations have been tentatively selected for these parts, the unit time value for each operation is obtained from the time-study department and entered on the form. The extension of these time values provides the first inkling of machine loads. From those initial indications, alternative methods are similarly applied and extended on the form and the results are compared as a basis for weighing the relative merits of optional processing methods. The comparison of the results thus obtained constitutes the *analysis of manufacturing methods.*

Selection of Machinery and Tooling

As the trial studies are being made, it is of the utmost importance to visualize the entire pattern of machine loads by types of machines. Except in mass-production plants, the machinery, equipment, and tooling being selected as the most suitable for the project may not be loaded sufficiently to justify their use. When the projected activity does not warrant the investment in a particular machine tool, it is often better economy to compromise on an otherwise available machine at a higher labor cost, which is more than offset by lower depreciation costs. Keeping these comparisons in the foreground throughout the preparation of preliminary estimates of operations and machine loads usually guards against such wasted effort at a later stage when the selected methods are found to be economically unsound.

4. DETERMINING THE LABOR COST OF AN OPERATION BEFORE FINAL SELECTION

Use Made of Time Values in Layout Work

The unit time value, supplied by the methods engineers for each operation (see Figure 63) and entered on the form illustrated in Figure 68 for the purpose of determining machine loads, supplies the structural data of the entire plant layout design. In other words, unit time values are to a plant layout plan what bricks, cement, and structural steel are to the construction plan of the factory building proper. A word on the determination of these time values will be of practical benefit in applying these time values to the production program for determining machine loads, selecting operations, and developing the plant layout.

0.001 Hour per Piece May Mean One Whole Machine

The importance of one thousandth of an hour (0.001) in time allowance per piece in mass production is illustrated in the chart shown in Figure 69, developed by the authors. For example, in an operation involving a time allowance of 0.012 of an hour per piece, the resulting machine-hours of work per year increase as follows for each increment of 0.001 of an hour in time allowance per piece for the number of pieces per year indicated (see Application 1 of Figure 69).

MACHINE HOURS PER YEAR

Number of Pieces per Year	When Time Allowance per Piece Is 0.012	When Time Allowance per Piece Is 0.013	Increase in Machine Hours for Each Increment of 0.001 Hour in Time Value
1,000	12	13	1
10,000	120	130	10
100,000	1,200	1,300	100
1,000,000	12,000	13,000	1,000
2,000,000	24,000	26,000	2,000

When production reaches 2,000,000 pieces a year, a difference of 0.001 of an hour in time allowance per piece amounts to 2,000 machine-hours, equivalent to the full time of one machine for the entire year, operating 40 hours a week for 50 weeks.

0.001 Hour per Piece May Mean $3,000 of Labor a Year

From a labor cost standpoint (see Application 4 on the chart), each increment of 0.001 of an hour in time allowance per piece increases the labor expenditure per year as follows when the labor rate is $1.50 an hour:

LABOR COST PER YEAR WHEN LABOR RATE IS $1.50 AN HOUR

Number of Pieces per Year	When Time Allowance per Piece Is 0.012	When Time Allowance per Piece Is 0.013	Increase in Labor Cost for Each Increment of 0.001 Hour in Time Value
1,000	$ 18	$ 19	$ 1
10,000	180	195	15
100,000	1,800	1,950	150
1,000,000	18,000	19,500	1,500
2,000,000	36,000	39,000	3,000

Again, when production involves 2,000,000 pieces a year, a difference of 0.001 of an hour in time allowance per piece means a cost differential of $3,000 when the labor rate is $1.50 an hour. Considerations of this nature greatly influence the selection of an operation in compiling the manufacturing layout data in Figure 68. When a multiplicity of parts and operations are involved in a plant layout, there is a tendency to by-pass these calculations in order to gain time in developing the layout. As a means of expediting these calculations, the **Labor Costimator** chart in Figure 69 was developed and placed on the market by the authors.

Quick Answers by Inspection

A quick way of arriving at an answer by mere inspection is illustrated in Application 5 on the chart. By simply locating the junction of the number of pieces per year with the labor rate per hour and extending this point to the scale at the right of the chart, one glance will indicate whether the operation in question should be: (*a*) given casual consideration; (*b*) given a careful study; or (*c*) subjected to an intensive study.

Other applications of the **Labor Costimator** in plant layout engineering and time-study work are illustrated in Applications 2, 3, and 6, which are not taken up at this time. The complete set of applications is as follows:

1. Machine-hours per year.
2. Time allowance per piece.
3. Number of pieces per year.
4. Labor expenditure per year.
5. Labor cost per 0.0001 hour per year.
6. Labor rate per hour.

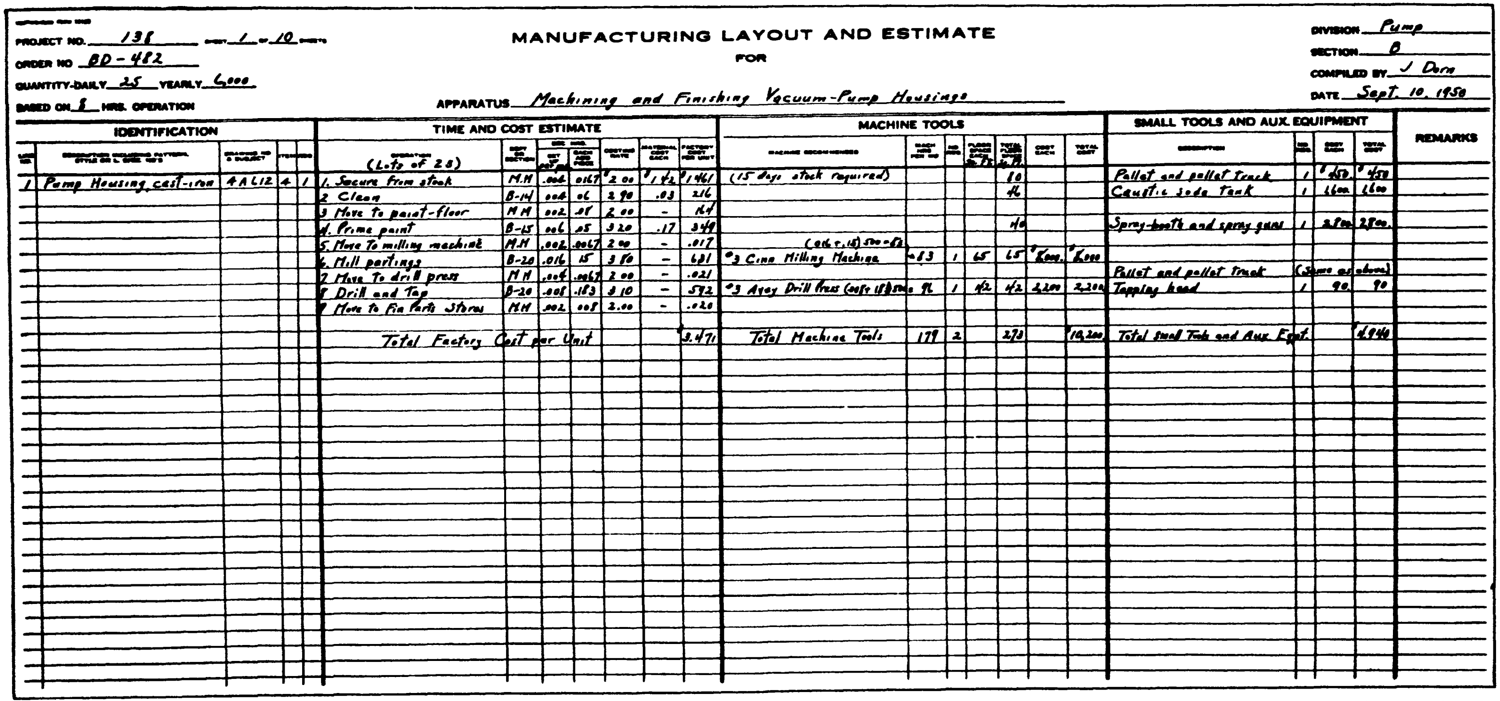
Where a large number of calculations are involved and a number of variable factors have to be considered from different angles, the **Labor Costimator** chart supplies these answers at a glance as readily as a simple calculation is found on a slide rule. This is particularly true when a given application, such as No. 1 for machine hours per year, is used repeatedly at varying rates. Once the first answer to a given application has been derived, an indefinite series of solutions may be obtained instantly by merely varying one or two of the factors in the given formula.

5. FINAL STUDIES OF OPERATION TIME, FACTORY COST, AND MACHINE COST

Selection of Best Manufacturing Method

From the preliminary estimates compiled and compared by operations on the form in Figure 68, a selection is made of the resulting best method from the standpoint of machine loads and labor cost. The method thus selected for each operation is transferred to a more comprehensive form, such as the manufacturing layout and estimate of Figure 70, for the purpose of evaluating the operating cost and investment cost of this particular method.

In selecting what appears to be the most logical manufacturing method out of a number of methods that inevitably come up for consideration, each method is thoroughly analyzed from a number of angles aside from time values and types of machine tools. As an example, the obvious best method of manufactur-



[illegible]

PROJECT NO. 138 SHEET 1 OF 10 SHEETS
ORDER NO BD-482
QUANTITY-DAILY 25 YEARLY 6000
BASED ON 8 HRS. OPERATION

MANUFACTURING LAYOUT AND ESTIMATE
FOR

APPARATUS Machining and Finishing Vacuum-Pump Housings

DIVISION Pump
SECTION B
COMPILED BY J Dorn
DATE Sept. 10, 1950

IDENTIFICATION					TIME AND COST ESTIMATE							MACHINE TOOLS							SMALL TOOLS AND AUX. EQUIPMENT				REMARKS
LINE NO.	DESCRIPTION INCLUDING PATTERN, STYLE OR L. DWG. NO'S	DRAWING NO. & SUBJECT	[illegible]	[illegible]	OPERATION (Lots of 25)	DEPT OR SECTION	STD. HRS. SET UP PER LOT	EACH ADD PIECE	COSTING RATE	MATERIAL COST EACH	FACTORY COST PER UNIT	MACHINE RECOMMENDED	MACH HRS PER MO	NO. REQ.	FLOOR SPACE EACH Sq. Ft.	TOTAL FLOOR SPACE Sq. Ft.	COST EACH	TOTAL COST	DESCRIPTION	NO. REQ.	COST EACH	TOTAL COST	
1	Pump Housing, cast-iron	4AL12	4	1	1. Secure from stock	M.H	.004	.0167	$2.00	$1.42	$1.461	(15 days stock required)				80			Pallet and pallet truck	1	$450.	$450	
					2 Clean	B-14	.004	.06	2.90	.03	216					46			Caustic soda Tank	1	1600.	1600	
					3 Move to paint-floor	M M	.002	.08	2.00	-	164												
					4. Prime paint	B-15	.006	.05	3.20	.17	349					40			Spray-booth and spray guns	1	2800.	2800.	
					5. Move to milling machine	M.H	.002	.0067	2.00	-	.017	(.016 + .15) 500 = 83											
					6. Mill partings	B-20	.016	.15	3.80	-	631	#3 Cinn Milling Machine	83	1	65	65	$8000.	$8000					
					7 Move to drill press	M H	.004	.0067	2.00	-	.021								Pallet and pallet truck	(Same as above)			
					8 Drill and Tap	B-20	.008	.183	3.10	-	592	#3 Avey Drill Press (.008 + .183) 500 =	96	1	42	42	2,200	2,200	Tapping head	1	90.	90	
					9 Move to Fin Parts Stores	MH	.002	.008	2.00	-	.020												
					Total Factory Cost per Unit						$3.471	Total Machine Tools	179	2		273		$10,200	Total Small Tools and Aux. Eqpt.			$4,940	

FIG. 70. *Cost estimate of product and tooling.* For a new product, or for a revised routing of an existing product, this form provides a simple but comprehensive method for estimating the total factory cost of the product, and of the added investment for machine tools, and for small tools and auxiliary equipment.

ing a given part, as judged solely from a processing standpoint, may be by sand-casting. But if the enterprise does not operate a foundry, there is no need of considering sand-casting any further, unless the company can justify the addition of a foundry to its facilities or unless the part is purchased from an outside foundry.

Factors Considered before Purchasing Parts

If the part is purchased a number of additional factors, such as the following, are to be considered, aside from the element of the purchase cost of the part:

1. Availability of the part at the time it is needed.
2. Transportation delays and costs.
3. Quantity that must be kept on inventory.
4. Handling and stores expense for the part.
5. Uniformity of quality.
6. Continuity of production by the suppliers.

When all these factors have been duly weighed, it may be found that, instead of sand-casting the part, it is more economical to manufacture it by permanent molding, die-casting, or fabricated design.

Selecting the Right Kind of Machine

In the field of machining operations proper, the margin of selection from a cost standpoint is even narrower than in foundry work. For example, a simple shaft finished by grinding may cost much less and have a higher-quality finish than the same shaft finished on an engine lathe. But unless the quantity of shafts to be finished is large enough to absorb this investment in the purchase of a grinder, the cost differential in favor of the grinder operation turns into a cost differential in favor of the existing engine lathe. When both the cutting and finishing are done on the engine lathe, only one machine is required. But when the cutting is done on the lathe and the finishing is done on the grinder, two machines are needed.

Thoroughness in determining the right way to do the job, of selecting the right kind of machine, and of ascertaining the number of each type of machine required stems directly from the accuracy employed in making the operation analysis, such as is laid out on the form in Figure 70.

Selecting the Raw Material for the Process

The operation analysis is commonly supplemented by a study of the materials specified and of their possible substitutes. To illustrate the use made of this information, let us consider a given part, the material for which lies in a choice between ferrous, non-ferrous, or non-metallic material. Here again, the obvious choice gravitates towards that material which commands the cheapest price.

However, cost to process the material, i. e., to shape, dimension, or finish the part from the material, might vary considerably for each kind of material. The higher differential in the processing cost of the material may far exceed its lower differential in purchase price. In this respect, the processing cost to a large extent determines the kind of material to be used.

A guide to the elements to be kept constantly in mind throughout the preparation of studies on operation analysis is given in Figure 71. A change in any one of these elementary factors frequently requires a compensating change in one or more of the other factors, according to the interrelationship indicated on the chart.

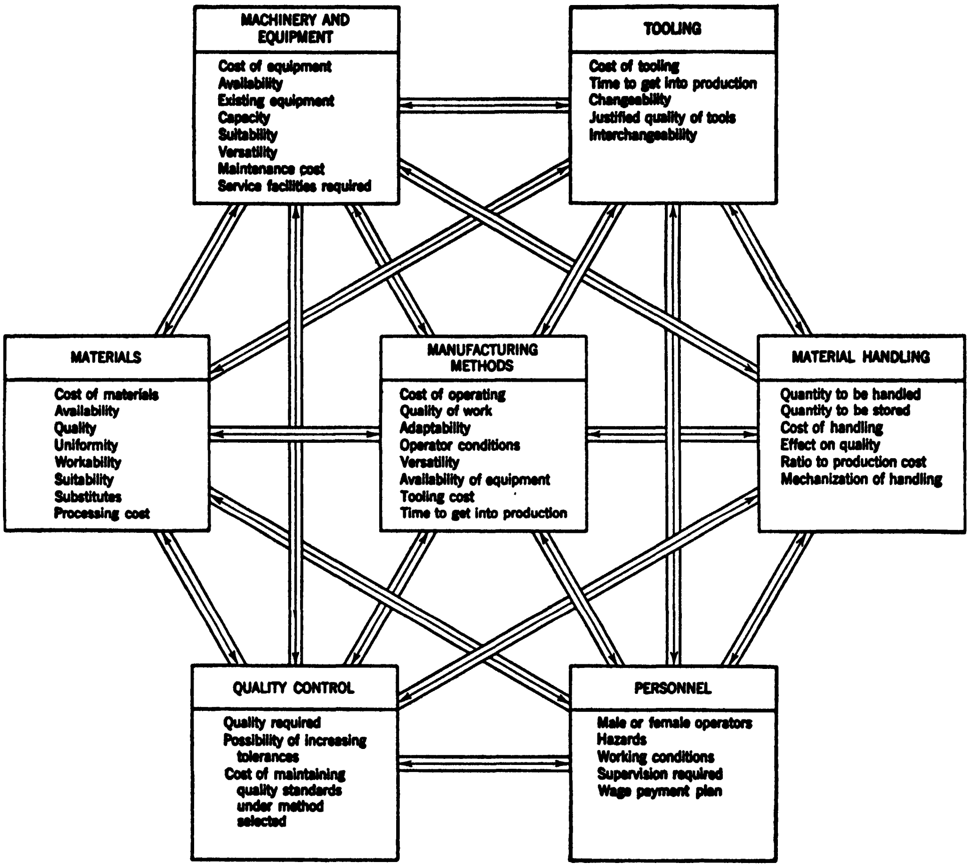


FIG. 71. *Guide to elements* of operation analysis.

A change in material, for example, may not affect the method or the equipment but may affect the tooling, material handling, or quality control. Also, a change in quality standards may affect tooling and time values. Then, too, a change in equipment may necessitate a change from a female to a male operator. Such changes could be illustrated indefinitely.

Every time a *material* or *method* is selected for a *trial study,* the entire array of factors needs to be scrutinized closely to observe the effect that such change may visit upon one or more of the factors and upon the operating cost, the investment required, and the contemplated layout design.

6. FUNCTIONS OF PROCESS FLOW CHARTS IN ROUTING OPERATIONS

Sequence of Production Steps through the Shop

The operation analysis and timing described thus far have been confined to operation elements and piece parts, irrespective of their sequence in the flow of operations. Before the actual layout is undertaken, a continuous sequence of processing and assembly steps necessary to convert the piece parts into finished assemblies is developed in order to establish the flow of work and to balance the operations at the various points along the flow.

Process Chart Symbols

These process flows are commonly traced in graphic form on process charts through the medium of the standard symbols shown in Figure 72. These symbols are interspersed as guideposts along the entire path of travel, from raw material to finished product.

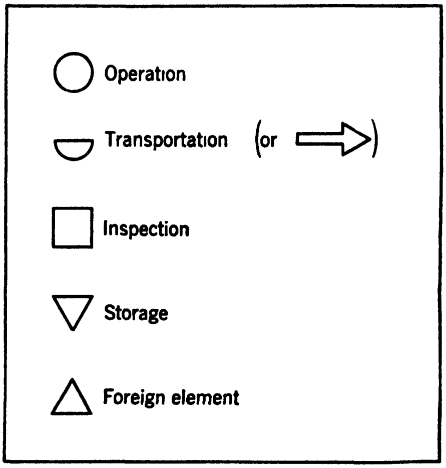


Fig. 72. *Process chart symbols.*

By means of these symbols, the steps in the manufacture of a product are indicated in proper sequence on the process chart. These symbols assist in singling out the different processes, transportation movements, inspection points, and stopping points for storage.

Process Flow Charts for Plant Layout

The main purpose of the process chart is to provide a preliminary diagram of the routing of the work for a part or assembly. By thus making a rough analysis of the various steps and of time values for each step, much time is saved in locating the operations, machinery, and equipment on the plant layout. Furthermore, process charts are indispensable in planning the locations and areas of machine groups and departments and in suggesting the general arrangement of the plant layout.

Several types of process charts have been developed for these purposes, the most common being (1) process flow charts, (2) isometric flow charts, and (3) pictographic flow charts. Process charts are used principally in developing plant layouts and are not to be confused with motion-study flow charts, which are used for analyzing the motions within an operation. Whereas the process chart analyzes the relationship between one operation and the next, the motion-study flow chart breaks down each operation into detailed movements of the operator's arm, fingers, etc.

The fundamental purpose of the various types of process charts is the same: to present graphically the flow of work from operation to operation and through

Distance Moved, in feet	Time Dec-Hours		Column 1
		△	Castings received from steel foundry 15 days after placing order
22	0.1	○ O-1	Unload from supplier's truck by receiving clerk and laborer
	16.0	▽ TS	Storage until ordered by machine shop
5	0.05	○ O-2	Load on to trailer
	1.5	▽ TS	Storage —waiting for tractor transportation
	0.03	○ O-3	Hook trailer to tractor train
225	0.38	○ T	Move to Group No. 1, Department 10
	0.03	○ O-4	Unhook trailer from tractor train
5	0.05	○ O-5	Unload trailer
	4.0	▽ TS	Storage —waiting for layout
	1.23 × 10 = 12.3	○ O-6	Layout casting for machining
	0.5	▽ TS	Storage —waiting for move man
15	0.1	○ T	Move to Group No. 4, Department 10
	4.0	▽ TS	Storage —waiting for planer
	0.653 × 10 = 6.53	○ O-7	Rough face-planer
	0.5	▽ TS	Storage —waiting for move man
16	0.1	○ T	Move to Group No. 2, Department 10
	4.0	▽ TS	Storage —waiting for milling
	0.804 × 10 = 8.04	○ O-8	Rough mill —2 operations
	0.5	▽ TS	Storage —waiting for move man
5	0.05	○ O-9	Load on to trailer
	1.5	▽ TS	Storage —waiting for tractor transportation
	0.03	○ O-10	Hook trailer to tractor train
368	0.45	○ T	Move to annealing furnace, Department 22
	10.0	▽ TS	Storage —waiting for annealing
10	0.2	○ O-11	Load into furnace
	8.0	○ O-12	Anneal
30	0.4	○ T	Move from furnace to sand blast by sand blast operator
			(Continued in col. 2)→

Distance Moved, in feet	Time Dec-Hours		Column 2 (Continued from col. 1)
	0.1 × 10 = 1.0	○ O-13	Clean by sand blasting
5	0.05	○ O-14	Load on to trailer by sand blast operator
	1.5	▽ TS	Storage —waiting for tractor transportation
	0.03	○ O-15	Hook trailer to tractor train
398	0.48	○ T	Move to Group No. 4, Department 10
	0.03	○ O-16	Unhook trailer from tractor train
5	0.05	○ O-17	Unload trailer
	4.0	▽ TS	Storage —waiting for planer
	0.412 × 10 = 4.12	○ O-18	Finish face-planer
	0.5	▽ TS	Storage —waiting for move man
16	0.1	○ T	Move to Group No. 2, Department 10
	4.0	▽ TS	Storage —waiting for milling
	1.025 × 10 = 10.25	○ O-19	Finish mill —2 operations
	0.5	▽ TS	Storage —waiting for move man
36	0.1	○ T	Move to Group No. 3, Department 10
	4.0	▽ TS	Storage —waiting for drilling
	0.484 × 10 = 4.84	○ O-20	Drill
	0.5	▽ TS	Storage —waiting for move man
28	0.10	○ T	Move to inspector
	2.0	▽ TS	Storage —waiting for inspector
	0.1 × 10 = 1.0	□ Ins. 1	Inspect cylinder head
	0.5	▽ TS	Storage —waiting for move man
5	0.05	○ O-21	Load on to trailer
	1.5	▽ TS	Storage —waiting for tractor transportation
	0.03	○ O-22	Hook trailer to tractor train
450	0.75	○ T	Move to assembly Department 12
	0.03	○ O-23	Unhook trailer from tractor train
25	0.11	○ O-24	Unload trailer at storeroom
	Indeterminate	▽ TS	Storage —awaiting assembly

FIG. 73. *Process flow chart* of operations, distance moved, and time values to manufacture an internal-combustion-engine cylinder head, from receipt of casting until assembly. (*Courtesy of Gaudreau, Rimbach & Associates, Pittsburgh.*)

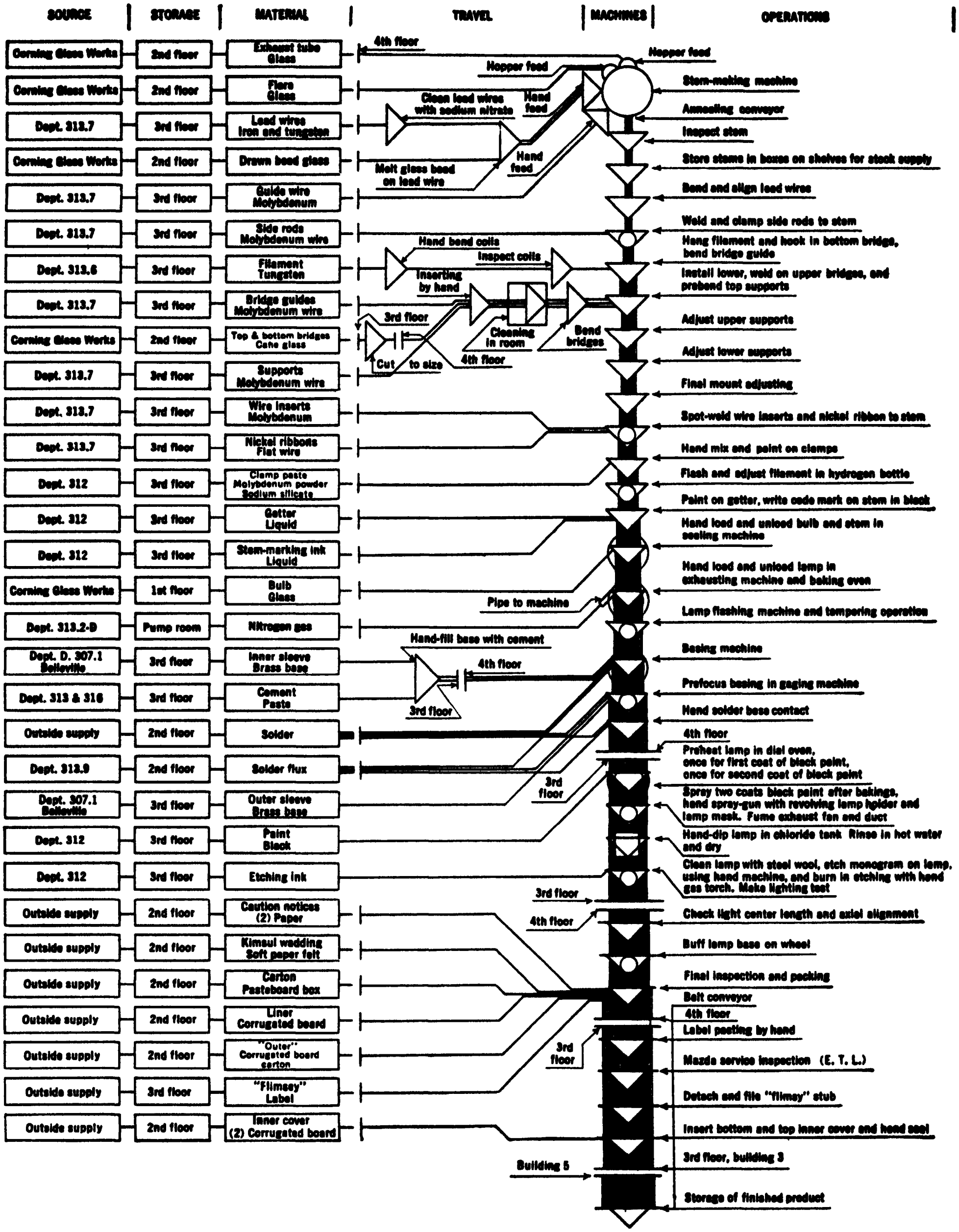
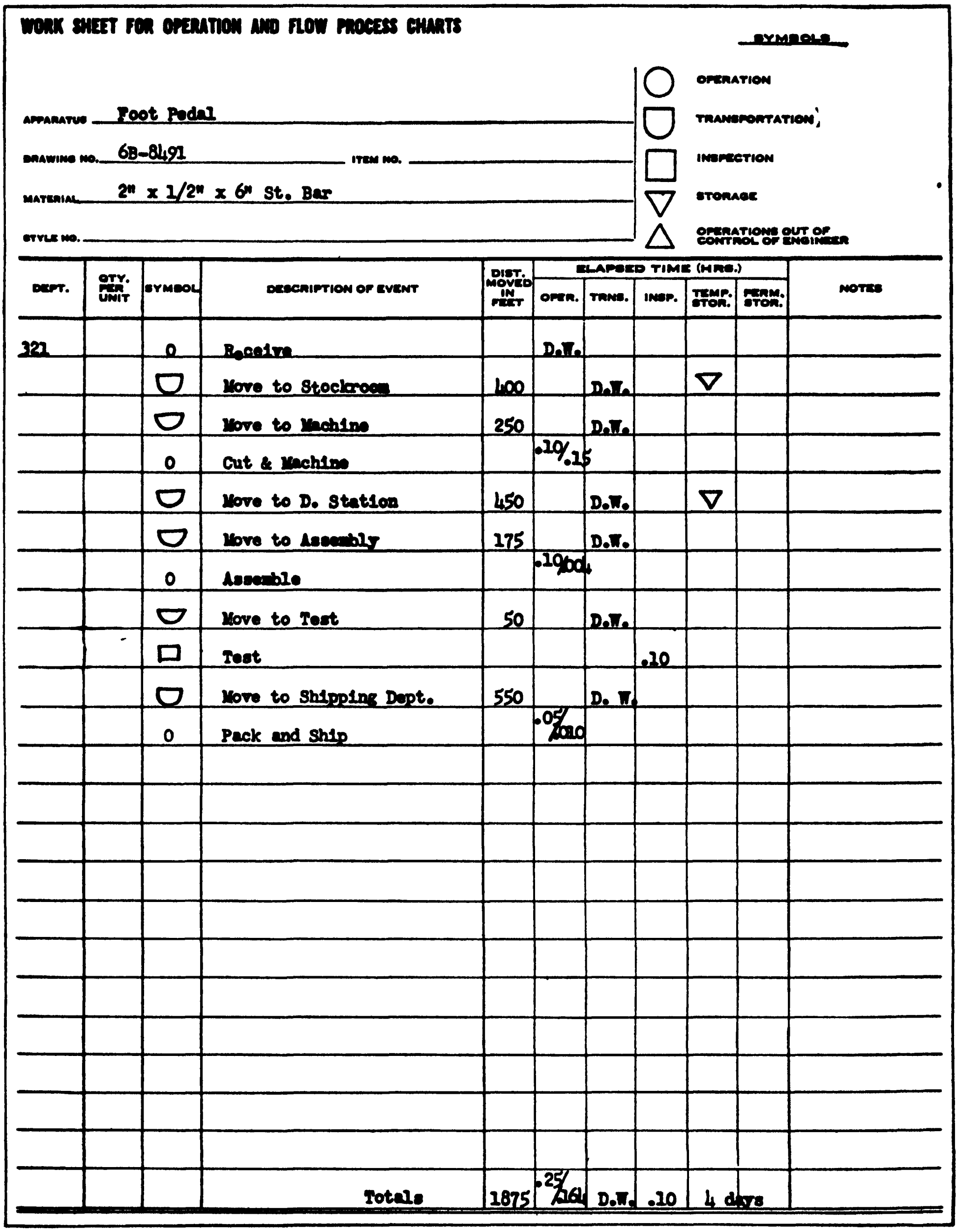

SOURCE
STORAGE
MATERIAL
TRAVEL
MACHINES
OPERATIONS
Corning Glass Works
2nd floor
Exhaust tube Glass
Corning Glass Works
2nd floor
Flare Glass
Dept. 313.7
3rd floor
Lead wires Iron and tungsten
Corning Glass Works
2nd floor
Drawn bead glass
Dept. 313.7
3rd floor
Guide wire Molybdenum
Dept. 313.7
3rd floor
Side rods Molybdenum wire
Dept. 313.6
3rd floor
Filament Tungsten
Dept. 313.7
3rd floor
Bridge guides Molybdenum wire
Corning Glass Works
2nd floor
Top & bottom bridges Cane glass
Dept. 313.7
3rd floor
Supports Molybdenum wire
Dept. 313.7
3rd floor
Wire inserts Molybdenum
Dept. 313.7
3rd floor
Nickel ribbons Flat wire
Dept. 312
3rd floor
Clamp paste Molybdenum powder Sodium silicate
Dept. 312
3rd floor
Getter Liquid
Dept. 312
3rd floor
Stem-marking ink Liquid
Corning Glass Works
1st floor
Bulb Glass
Dept. 313.2-D
Pump room
Nitrogen gas
Dept. D. 307.1 Belleville
3rd floor
Inner sleeve Brass base
Dept. 313 & 316
3rd floor
Cement Paste
Outside supply
2nd floor
Solder
Dept. 313.9
2nd floor
Solder flux
Dept. 307.1 Belleville
3rd floor
Outer sleeve Brass base
Dept. 312
3rd floor
Paint Black
Dept. 312
3rd floor
Etching ink
Outside supply
2nd floor
Caution notices (2) Paper
Outside supply
2nd floor
Kimsul wadding Soft paper felt
Outside supply
2nd floor
Carton Pasteboard box
Outside supply
2nd floor
Liner Corrugated board
Outside supply
2nd floor
"Outer" Corrugated board carton
Outside supply
3rd floor
"Flimsey" Label
Outside supply
2nd floor
Inner cover (2) Corrugated board
4th floor
Hopper feed
Clean lead wires with sodium nitrate
Hand feed
Hand feed
Melt glass bead on lead wire
Hand bend coils
Inspect coils
Inserting by hand
3rd floor
Cleaning in room
Bend bridges
Cut
to size
4th floor
Pipe to machine
Hand-fill base with cement
4th floor
3rd floor
3rd floor
3rd floor
4th floor
3rd floor
Building 5
Hopper feed
Stem-making machine
Annealing conveyor
Inspect stem
Store stems in boxes on shelves for stock supply
Bend and align lead wires
Weld and clamp side rods to stem
Hang filament and hook in bottom bridge, bend bridge guide
Install lower, weld on upper bridges, and prebend top supports
Adjust upper supports
Adjust lower supports
Final mount adjusting
Spot-weld wire inserts and nickel ribbon to stem
Hand mix and paint on clamps
Flash and adjust filament in hydrogen bottle
Paint on getter, write code mark on stem in black
Hand load and unload bulb and stem in sealing machine
Hand load and unload lamp in exhausting machine and baking oven
Lamp flashing machine and tempering operation
Basing machine
Prefocus basing in gaging machine
Hand solder base contact
4th floor
Preheat lamp in dial oven, once for first coat of black paint, once for second coat of black paint
Spray two coats black paint after bakings, hand spray-gun with revolving lamp holder and lamp mask. Fume exhaust fan and duct
Hand-dip lamp in chloride tank Rinse in hot water and dry
Clean lamp with steel wool, etch monogram on lamp, using hand machine, and burn in etching with hand gas torch. Make lighting test
Check light center length and axial alignment
Buff lamp base on wheel
Final inspection and packing
Belt conveyor
4th floor
Label pasting by hand
Mazda service inspection (E. T. L.)
Detach and file "flimsy" stub
Insert bottom and top inner cover and hand seal
3rd floor, building 3
Storage of finished product

FIG. 74. *Production flow chart* of materials, through machines, by operations, to manufacture a 750-watt biplane projection incandescent lamp. (*Courtesy of Westinghouse Electric Corporation, Pittsburgh.*)



WORK SHEET FOR OPERATION AND FLOW PROCESS CHARTS

APPARATUS Foot Pedal
DRAWING NO. 6B-8491 ITEM NO.
MATERIAL 2" x 1/2" x 6" St. Bar
STYLE NO.

SYMBOLS
○ OPERATION
◡ TRANSPORTATION
□ INSPECTION
▽ STORAGE
△ OPERATIONS OUT OF CONTROL OF ENGINEER

DEPT.	QTY. PER UNIT	SYMBOL	DESCRIPTION OF EVENT	DIST. MOVED IN FEET	ELAPSED TIME (HRS.)					NOTES
					OPER.	TRNS.	INSP.	TEMP. STOR.	PERM. STOR.	
321		0	Receive		D.W.					
		◡	Move to Stockroom	400		D.W.		▽		
		◡	Move to Machine	250		D.W.				
		0	Cut & Machine		.10/.15					
		◡	Move to D. Station	450		D.W.		▽		
		◡	Move to Assembly	175		D.W.				
		0	Assemble		.10/.004					
		◡	Move to Test	50		D.W.				
		□	Test				.10			
		◡	Move to Shipping Dept.	550		D. W.				
		0	Pack and Ship		.05/.010					
			Totals	1875	.25/.164	D.W.	.10	4 days		

FIG. 75. *Basic information for developing flow of materials* as illustrated on operation analysis (Figure 57).

storage and inspection points. The types differ mainly in the degree of refinement and comprehensiveness of the presentation.

The simplest type of process chart, and the one most frequently used, is the vertical line of symbols shown in Figure 73. This diagram also contains the distance moved from point to point, and the operating time at each point.

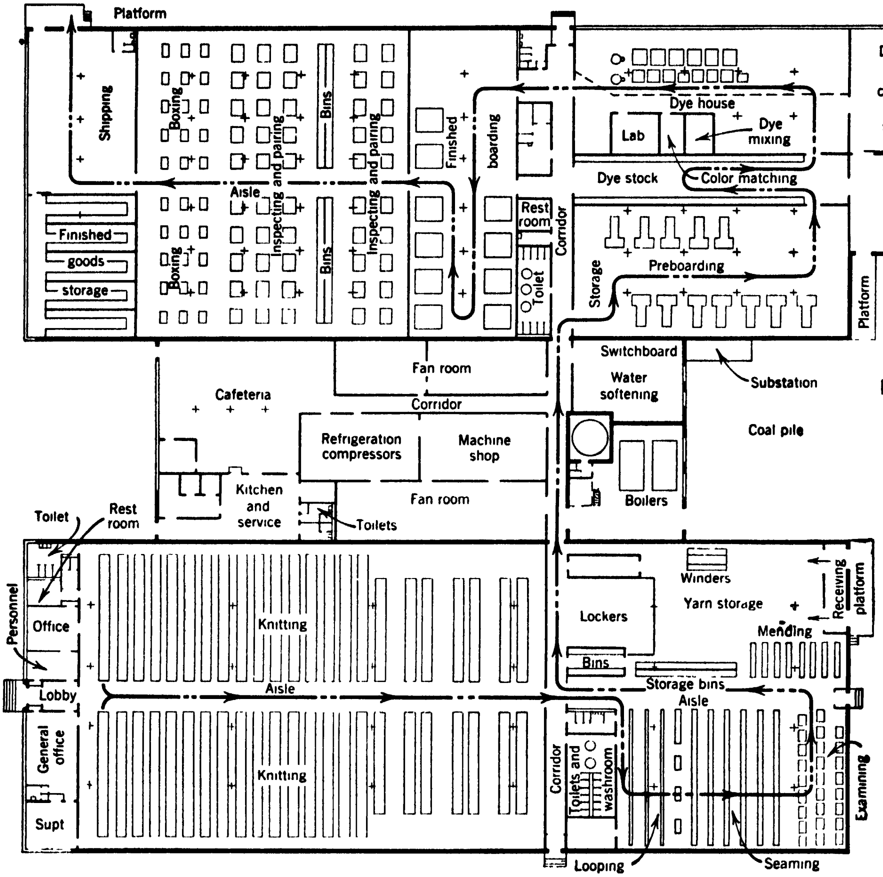


FIG. 76. *Equipment layout of a hosiery mill* The ultimate use of flow charts in plant layout engineering is illustrated in this equipment layout of the Humboldt Full Fashioned Hosiery Mills, Humboldt, Tenn (*Courtesy of Lockwood Greene Engineers, Inc., New York.*)

A more elaborate type of process chart appears in Figure 74. This type does not show the distance traveled or the time values. It is used principally for studying processes and flows rather than for analyzing operations. The isometric flow chart is used wherever the contemplated layout extends into two or more floor levels.

A simple and practical form for drawing flow charts of processes and operations, together with all distances moved and elapsed time at each point, is shown in Figure 75. The operations can be listed in sequence with travel distance and elapsed time for each operation. Furthermore, all foreign and non-productive operations can also be listed and symbolized. When the chart is filled out, each column of symbols can be totaled. In this way, the number of productive operations can be shown, together with the transportation movements, inspection points, and storages required to complete each productive operation.

Construction of Process Flow Charts

For intensive study, flow diagrams of this type aid the plant layout engineer in visualizing the flow of work, detecting backtracking, spotting bottlenecks in production, and noticing excessive distances in transportation. Flow diagrams of several different possibilities for a given sequence of operations may be roughed out quickly without involving elaborate detail work. When properly constructed and analyzed, flow diagrams point the way to the ultimate plant layout design.

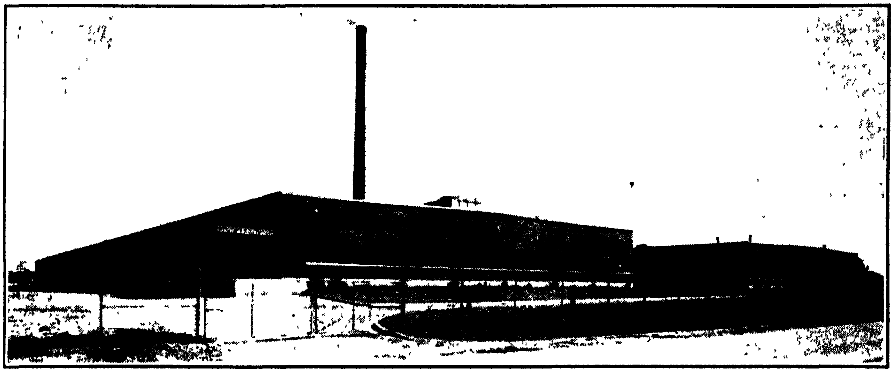


FIG. 77 *Single-story hosiery mill* of the Humboldt Full Fashioned Hosiery Mills, Humboldt, Tenn., described in the equipment layout drawing in Figure 76. (*Courtesy of Lockwood Greene Engineers, Inc., New York.*)

In constructing a process flow chart, the ultimate objective must be kept in mind at all times. It is necessary to know at the outset what the chart is intended to show when completed. Once the chart has been started, its growth in size should not be allowed to dissuade the engineer from developing it to completion. It is not uncommon to take the entire wall of a room for the purpose of constructing a flow chart. To facilitate the making of a more realistic study of the apparatus to be manufactured in the layout, gigantic charts are often made with the actual component part attached to the starting point of each flow line, and the finished part exposed at the terminal of the line. The operations required to manufacture the part are fully recorded along the line.

The ultimate use of flow charts in plant layout engineering is illustrated in Figure 76, in the equipment layout of a hosiery mill. A photograph of the actual hosiery mill described in the equipment layout drawing is shown in Figure 77, where the two parallel wings of the plant are clearly recognizable.

CHAPTER X

Planning and Equipping the Work Station

1. WORK-STATION LAYOUTS FOR PLANNING THE PLANT LAYOUT

Short-Cut Methods of Shuffling Machine Templates

In preparing plant layouts, the procedure is often mistakenly confined to the following cursory steps:

1. Determining the principal items of equipment necessary for the layout.
2. Making templates of these items.
3. Arranging the templates on a floor plan until the desired layout plan has been obtained.

The arrangement thus obtained by merely shuffling templates around a floor plan is thereupon construed as a finished layout design.

This short-cut method has often led to untold penalties in actual operations after the equipment has been installed. It has invariably given rise to permanent excessive costs of operations which often have wiped out all the profit that the installation could have yielded from a scientific layout.

Plant layouts literally thrown together in this superficial fashion fail to deal with the fact that, by itself, the equipment template, representing the unit of equipment, such as a milling machine, does not cover the entire area of the work station. This may be observed in Figure 15, illustrating the work-station layout for a milling machine. The machine by itself does not take account, in this case, of the workbench, two truck skids, and the tool locker required as auxiliary units for the operation of the machine.

Auxiliary Units of Equipment

There are numerous auxiliary items of equipment needed at a machine to service it, and many of these items require independent floor space. Items such as cutters, arbors, index heads, and rotary tables are examples of auxiliary units to a machine tool.

The layout template of a machine represents only the amount of floor space occupied by the machine itself and its overhang. It does not provide working space for the operator, nor for the tool rack, workbench, conveyor station, and whatever other auxiliary equipment he may need. Nor does it provide room for skid platforms which store the work in process before and after he performs the machine operations. The entire area occupied by the machine, the operator, the auxiliary equipment, and the work material is called a *work station.* With a balanced machine capacity at various operation points in a production line, very little storage space, and perhaps little aisle space, will be needed.

The area occupied by the machine is therefore but a portion of the area taken up by its work station. In the case of one size of a Milwaukee Horizontal Mill, for example, the floor area for the work station is 245 square feet, whereas for the machine alone it is only 116 square feet, or but 43% of the work station area. The work station for one type of a Norton Cylindrical Grinder would occupy 243 square feet, but the machine itself requires only 94 square feet, or 39%.

Variable Boundaries of Work Stations

If the boundaries and equipment contents of a work station did not vary with the type of product and with the type of machine operations performed, a template of the entire work station area could be used instead of one for the machine only. Since the machine is the only fixed area in the work station, statistics must be compiled for the remaining portions of the work-station area.

In actual practice a separate layout is made for each work station to indicate the proper position of each piece of equipment and the over-all area required by the station. These work-station layouts are then placed adjacent to each other, in proper sequence, in making the floor layout. The location occupied by the machine itself is then identified by placing a template on the work-station layout.

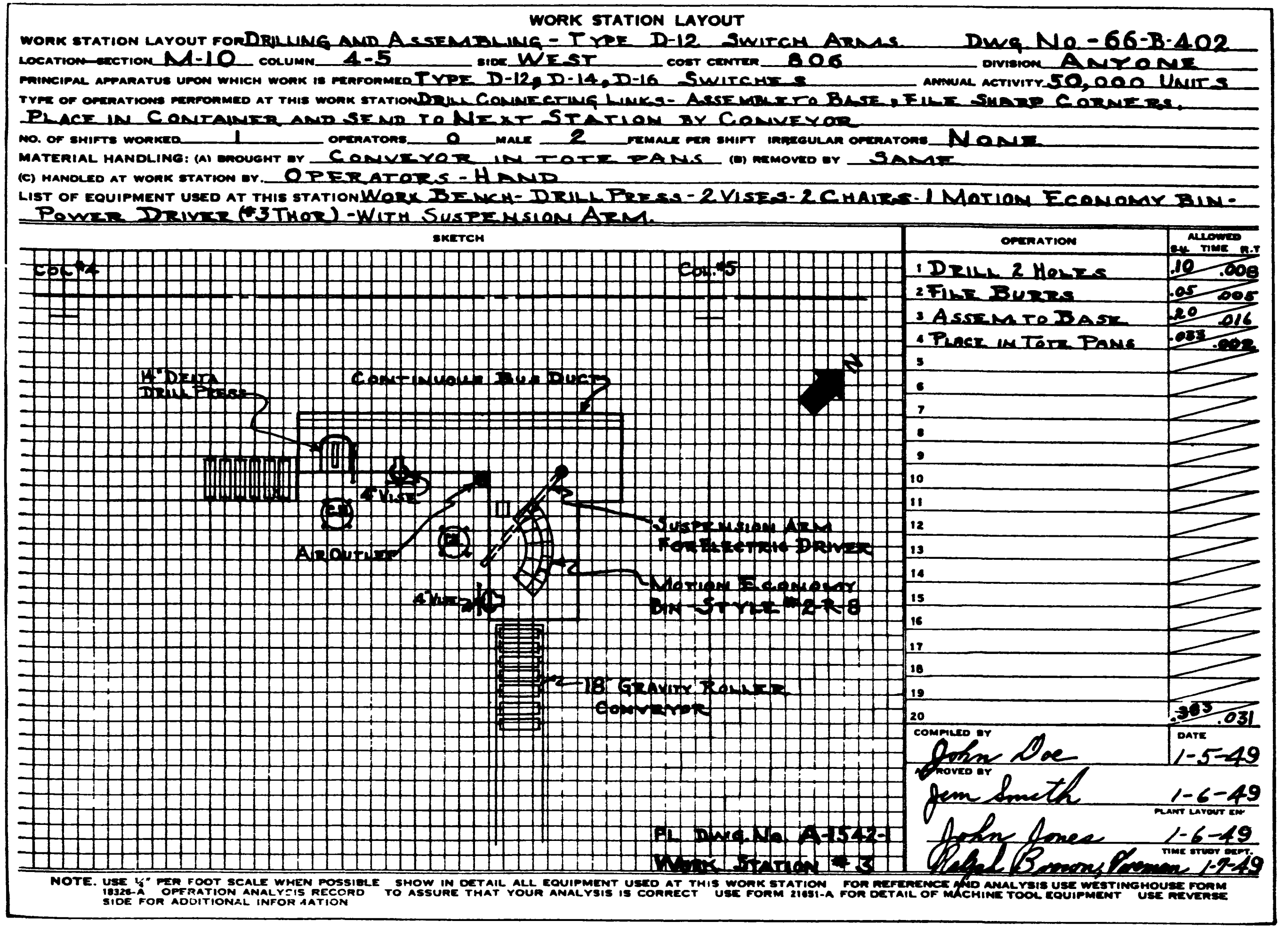
Standard Form for Work-Station Layouts

Work-station layouts for a given plant layout are best made on standard forms and drawn to the same scale used on the final plant layout. The scale of ¼ inch = 1 foot has been generally found the most practical. A simple type of standard form used for work-station layouts is illustrated in Figure 78. When printed on light paper of about 13-pound rag bond, this form can be readily reproduced by blueprinting or similar process to provide additional copies.

How Work-Station Layouts Are Used

The use of work-station layouts not only aids in planning the layout, but provides the time-study men, process engineers, tool engineers, quality control personnel, etc., with a complete preview of the equipment requirements at each operator's station. From these work-station layouts, time values can be estimated accurately in advance and tools can be ordered before actual production. These layouts also permit handling methods to be carefully predetermined for each handling or motion.

Last but not least, the work-station layouts eliminate the hazard of later embarrassment, when the layout is actually installed, arising from the lack of space for the minor things usually overlooked in the planning stage.



WORK STATION LAYOUT

WORK STATION LAYOUT FOR DRILLING AND ASSEMBLING - TYPE D-12 SWITCH ARMS DWG. NO - 66-B-402

LOCATION ~~SECTION~~ M-10 COLUMN 4-5 SIDE WEST COST CENTER 806 DIVISION ANYONE

PRINCIPAL APPARATUS UPON WHICH WORK IS PERFORMED TYPE D-12, D-14, D-16 SWITCHES ANNUAL ACTIVITY 50,000 UNITS

TYPE OF OPERATIONS PERFORMED AT THIS WORK STATION DRILL CONNECTING LINKS - ASSEMBLE TO BASE, FILE SHARP CORNERS. PLACE IN CONTAINER AND SEND TO NEXT STATION BY CONVEYOR

NO. OF SHIFTS WORKED 1 OPERATORS 0 MALE 2 FEMALE PER SHIFT IRREGULAR OPERATORS NONE

MATERIAL HANDLING: (A) BROUGHT BY CONVEYOR IN TOTE PANS (B) REMOVED BY SAME

(C) HANDLED AT WORK STATION BY OPERATORS - HAND

LIST OF EQUIPMENT USED AT THIS STATION WORK BENCH - DRILL PRESS - 2 VISES - 2 CHAIRS - 1 MOTION ECONOMY BIN - POWER DRIVER (#3 THOR) - WITH SUSPENSION ARM.

SKETCH

OPERATION	ALLOWED SL TIME	R.T
1 DRILL 2 HOLES	.10	.008
2 FILE BURRS	.05	.005
3 ASSEM. TO BASE	.20	.016
4 PLACE IN TOTE PANS	.033	.002
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		
18		
19		
20	.383	.031

COMPILED BY John Doe	DATE 1-5-49
APPROVED BY Jem Smith	1-6-49
PLANT LAYOUT ENG. John Jones	1-6-49
TIME STUDY DEPT. Ralph Bowman, Foreman	1-7-49

NOTE. USE ¼" PER FOOT SCALE WHEN POSSIBLE SHOW IN DETAIL ALL EQUIPMENT USED AT THIS WORK STATION TO ASSURE THAT YOUR ANALYSIS IS CORRECT FOR REFERENCE AND ANALYSIS USE WESTINGHOUSE FORM 18326-A OPERATION ANALYSIS RECORD USE FORM 21651-A FOR DETAIL OF MACHINE TOOL EQUIPMENT USE REVERSE SIDE FOR ADDITIONAL INFORMATION

FIG. 78. *Work-station layout* prepared, as required, for single units of existing machinery and equipment, and for all additional machinery and equipment required for the projected output.

2. METHODS ENGINEERING PRECEDING THE DESIGN OF WORK STATIONS

Confining Methods Studies to Principal Operations

Before designing work stations or applying tentative time values to the operations, a methods study of each *principal operation* should be made. This need not entail an intensive time and motion study or the use of elaborate equipment for motion pictures. Under ordinary circumstances, particularly when the operations are comparatively simple, a practical mental review of the operations will suggest significant improvements in the manufacturing methods selected. If a new layout is being made of existing operations, a satisfactory plan to follow is to observe the operation carefully, and, for each element of the operation, to attempt to answer the reason for its very existence. In other words, "Why is this or that particular motion necessary?"

The analytical steps generally followed by the methods engineer in developing a work station are outlined in Figure 79. Wherever justifiable, he makes use of such engineering tools as operation analysis sheets, flow charts, motion pictures, and job specifications.

SCIENTIFIC APPROACH	PRODUCTS OBTAINED	OPERATIONS PERFORMED	TOOLS USED
METHODS ENGINEERING	ANALYSIS	Mental, by observation	
		Written	Analysis sheet
		Process charts	Flow charts Man and machine charts Operation process charts
		Motion study	Analysis and observation Motion picture analysis Motion time analysis
	STANDARDIZATION	Equipment Conditions Methods	Verbal instructions Written instructions Motion-picture training
	TIME STUDY		

FIG. 79. *Fundamental concepts* of methods engineering analysis.

Points Considered in Analyzing a Work Station

Detailed motion studies may reveal possibilities of shortening or eliminating certain motions in an operation. Such detail as the proper placement of tote pans or parts containers at the work station may materially affect the time required to perform an operation. A study of the sequence of operations may reduce the number of operations on the part or reduce the time on some operations which follow the one performed at the work station under study.

The tools may be found inadequate or in need of improvement before operations can begin. The need for special tools is thoroughly analyzed at this point. Perhaps a minor redesign of the product will permit the use of standard tools instead of special ones. Other matters also considered in analyzing a work station are setup time, inspection methods, quality control, and material handling.

3. METHODS AND TIME STUDY TO DETERMINE MOTION ECONOMY

Functions of Scientific Time Studies

To find the most economical way of performing an operation at a work station, an analysis must be made of the material worked on, the tools used, the equipment operated, and the manufacturing methods followed. The scientific method of making this analysis is through a motion and time study. Such a study analyzes all the movements made by the operator at the work station; reveals the unnecessary motions; and arranges the surviving motions in proper sequence. Time studies also aid in balancing the extent of work and developing rhythmic operations.

The primary and ultimate purpose of a time study is to record operating time and to compute the time it *should* take to perform a certain job or operation. The recording is usually made from a stop watch, with the aid of motion-picture equipment in some of the larger plants.

A time study normally consists of three stages: (1) preliminaries, (2) observations, and (3) computations and conclusions. A descriptive outline of the technique covered in each stage of a methods and time study is shown in Figure 80.

Observations Made for a Metal-Cutting Machine

The observations made during the course of a methods study made for a metal-cutting machine work station include an analysis of the following operating conditions surrounding the task:

1. Correctness of the machine speed.
2. Suitability and condition of the tools.
3. Depth of cut taken into the material.
4. Operating condition of the machine.
5. Proficiency of the operator.
6. Useless motions by the operator.
7. Material handling at the work station.
8. Light, heat, ventilation, and plant housekeeping.

Substitute Methods of Rate-Setting

Four other methods of setting rates are used instead of detailed time studies, usually in plants where standardization has not reached wide application. These four substitute methods, together with their limitations, are:

a. **Making a pilot run.** When trial lots are processed, time taken to do the work is **actual,** regardless of the efficiency of the operation. The time it *should* take to perform the task is another matter, however, which is not governed by **actual** time.

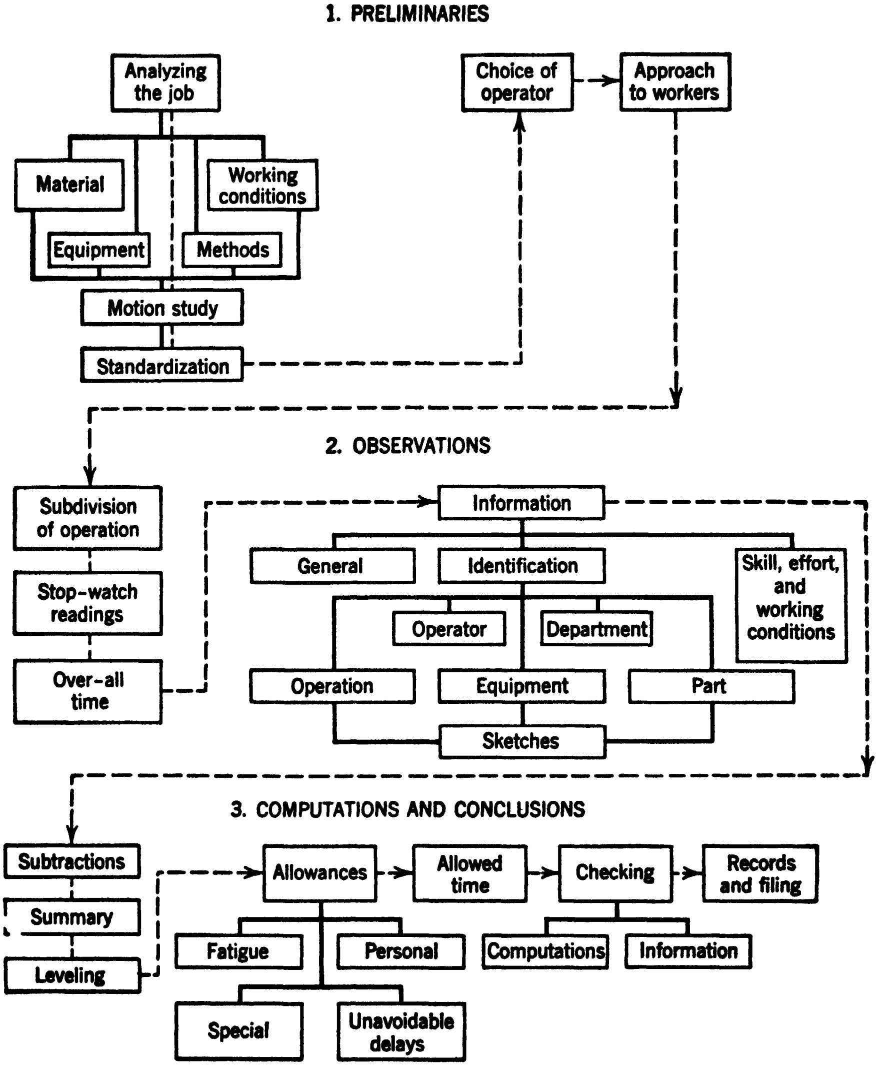


FIG. 80. The technique of a methods-and-time study.

b. **Estimate by the foreman.** Estimates of this nature usually contain guesswork and overlook many of the conditions surrounding the operation.

c. **Records of past performance.** Time allowances determined in the past offer little incentive to efficient operators, whereas the poorer workmen stand to profit greatly by simply coming up to par, thereby capitalizing on past incompetence.

d. **Standard indexed data** supplied by equipment manufacturers or set up in formula form. At best, this information provides only an approximation of time-study rates. Because of the variable factors in equipment, tools, methods, operators, and conditions surrounding the operation in different plants, indexed data do not yet permit an accurate determination of the time required to do an operation.

In view of the limitations indicated above foı the four substitute methods of rate setting, industry in general still favors the use of the stop-watch study as the most practical method of timing the operations at a work station. In estimating time values for plant layout purposes, however, independent of rate-setting, almost any one of these four substitute time-study methods is sometimes used. They are not recommended if any degree of accuracy is required.

4. DESIGNING WORK AREAS REQUIRING THE MINIMUM OF MOTIONS

Minimum and Simplest Motions

In designing the work station, the **work area** for the operator in the work station is so planned that the motions required of him are held not only at a minimum but also within the least complicated classes of hand motions. The simplest classes of hand motions are those limiting the effort to the fingers, or to the fingers, wrists, and forearm combined. When the upper arm and the body come into play, the motions become more complex and involved.

Ranges for Hand Motions

As for the range of the work area proper, Figure 81 illustrates the most effective normal and maximum areas for the hands when working in a horizontal plane.

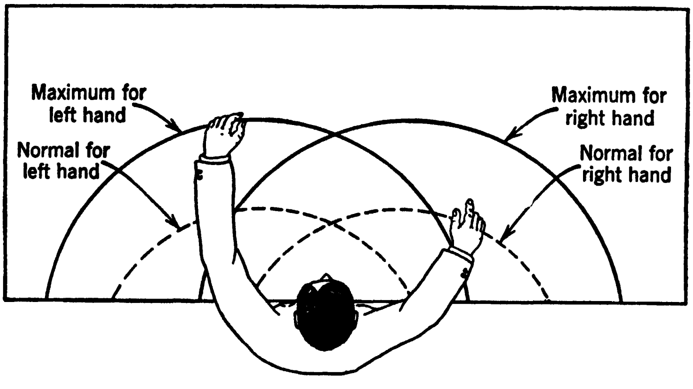


FIG. 81. *Working areas for hands.* Normal and maximum working areas for the hands in horizontal plane.

If all operations could be performed within these areas, the operators would reach the peak of motion utilization and efficiency, other factors being equal. The attainment of this ideal in the work-station layout is not so difficult as is often imagined. Figure 82 shows how simple and inexpensive bins can be arranged

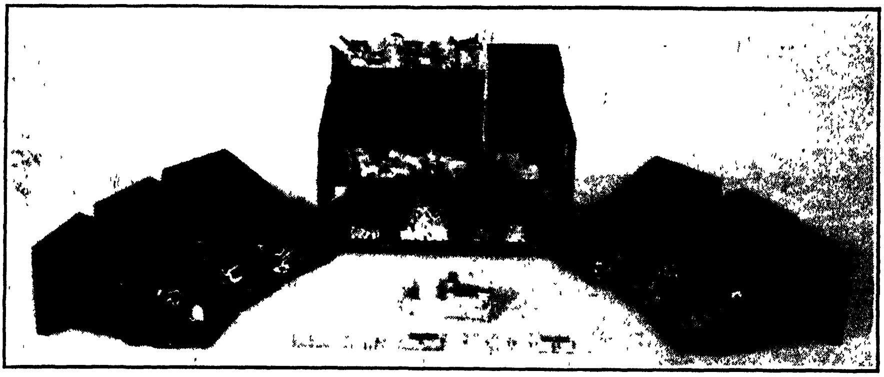


FIG. 82. *Quickly arranged motion-economy work station.* The bins are portable units in which material can be stored in lot quantities. By taking the proper number of bin units and arranging them as shown on an ordinary work table, a work station is set up which employs the principle referred to in Figure 81. Such a station can be set up in a few minutes.

quickly to provide a work station that approaches this ideal principle in design. The entire setup can be made in a few minutes without elaborate planning.

Material-Handling Facilities in a Work Station

The same principle is applied to a machine work station in Figure 83 where the handling facilities have been arranged to permit the machine operator to work with a minimum of unnecessary motions. The work station has been so laid out that the operator can perform all his functions in a small radius and be left free to apply most of his attention to the operation of the machine itself rather than be concerned with material handling. The automatic chucking and drilling machines in this work station have been so arranged that the work is brought to, and removed from, the work station, almost to the very point of the work area itself.

Advantages of a Well-Planned Work Station

In all work station layouts, the plant layout engineer should keep in mind that the *time required* and the *distance traveled* in the course of manufacturing a product directly affect the production cost of that product. A well-planned work station offers the following advantages:

1. Eliminates wasted motions in handling material.
2. Increases output without increasing effort.
3. Raises the morale of the worker.
4. Improves the housekeeping of the plant.
5. Permits easier supervision.
6. Reduces fatigue of operation.
7. Keeps work spoilage at a minimum.

Other equipment, such as adjustable chairs with back rests, fluorescent lighting, and proper heating and ventilation, aids materially in building up operating efficiency and employee morale.

FIG. 83. *Handling facilities at work station.* The principle of work-station layout has been applied so that the operator can perform all his functions in a small radius and apply most of his attention to the operation of the machine itself without being concerned with material handling. (*Courtesy of Westinghouse Corporation, Pittsburgh.*)

5. DETERMINING THE OUTPUT CAPACITY OF WORK STATIONS

Subdivisions of a Factory Layout

As already indicated in Chapter III, a work station does not always have only one operator and one machine in it, besides storage space for work in process and supplementary apparatus. An operator may tend a group of machines, or one machine may be tended by a group of operators. The working area then becomes something more than a work station. It is then considered a production center. A number of production centers constitute a labor group, and a number of labor groups usually make up the cost center used by the accounting department. A number of cost centers make up a shop department, and a number of shop departments become a production line.

In gathering statistics on production it is necessary to keep these subdivisions clearly in mind, because production statistics are usually available only in terms of units of finished apparatus in a given production line. A factory layout, therefore, is principally a succession of production centers planned in detail on individual work-station layouts.

Output Capacity of Production Centers and Work Stations

The capacity of each production center must be known, so that a sufficient number of each kind may be provided for in the layout to maintain a balance in the flow of production. Time studies are recognized as the best source for securing this information. The productive capacity of all equipment in the layout should be known. The output obtainable from the layout would be difficult to determine without an accurate knowledge of the capacity of each production center and work station.

The work-station layout eventually becomes the basis for setting up the machine load chart in production control. The coding of machines and production centers is an important function of the more advanced type of production control. The dispatch stations and material handlers depend on these indices for their guidance. In practice, the foreman makes a daily survey of each work station to determine the number of jobs in process at each work station, the stations that are idle, and the amount of direct labor that has been assigned to each station.

6. SERVICE FACILITIES REQUIRED WITHIN WORK STATIONS

Material-Handling Facilities

After the necessary time studies have been made to determine the elements of the principal operations, the design of the work station constitutes the first major starting point in planning the plant layout. The material-handling facilities for each work station must be integrated into an over-all system serving a number of successive work stations and at the same time providing for the specific requirements within each station. An illustration of the necessity for this prerequisite in work-station design is given in Figure 84. This particular work station utilizes an indexing fixture, an apron conveyor, and special racks for storing work in process used in making porcelain insulators. By making the material easily accessible to the operator, the amount of manual material handling at the work station is kept at a minimum.

The material used at the workplace must be brought there from somewhere and later taken away to somewhere else in the plant. Transporting material to and from a work station is accomplished in several ways, such as by truck skid, by conveyor, by monorail, by gravity chute, and by sliding along a workbench, to name only a few methods. Containers used in the conveyance of this material may consist of several types, such as tote boxes, skid boxes, breadpans, reels, rolls, trays, etc.

Storing Material at Work Stations

Material received at the work station has to be stored there temporarily while the operation is being performed. Provision has to be made for storing the material within easy reach of the operator if manual material handling is to be kept at a minimum. A fully automatic bar feed designed to eliminate manual loading on screw machines is illustrated in Figure 85. Space for the operator's tools must also be allowed for in the work area, and a workbench may also be required in the area.

When the operator does not have to search-find-select materials for an operation but can blindly or subconsciously reach and grasp each part, he develops a stride and a sort of "mechanical sense" which greatly lessen effort and fatigue. He is thereby enabled to increase his output and earnings without increasing his effort. The storage plan at the work station permits the operator's two hands to be kept productively engaged a maximum of the time.

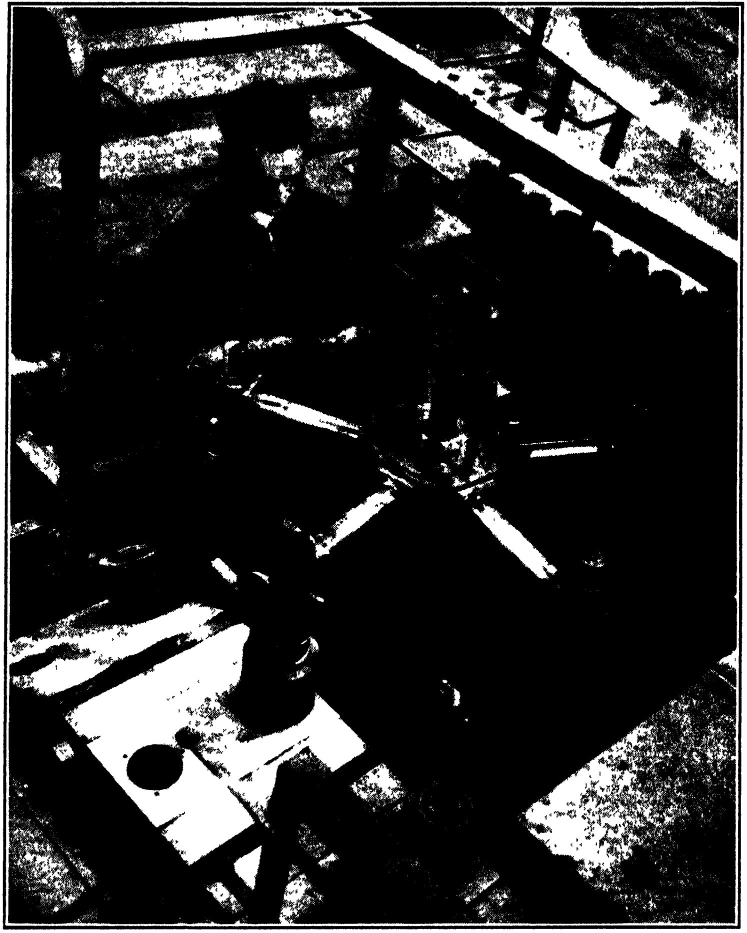


FIG. 84. *Work station* utilizing an indexing fixture, an apron conveyor, and special racks for work material used in making porcelain insulators.

Workbenches

The area normally allowed as bench space for an operator is 36 inches in length by 30 inches in depth by 34 inches in height. The bench top is normally made of 2-inch pine planking covered with hardwood or ¼-inch pressed wood edged with a $\frac{3}{8}$-inch molding. For special purposes the bench top may be of metal. The bench is usually equipped with metal legs. Some workbenches range from 6 to 12 feet in length, depending upon the number of operators to be accommodated.

The workbench area allowed within a work station should include provision for tools, fixtures, parts storage, and the space utilized for productive work.

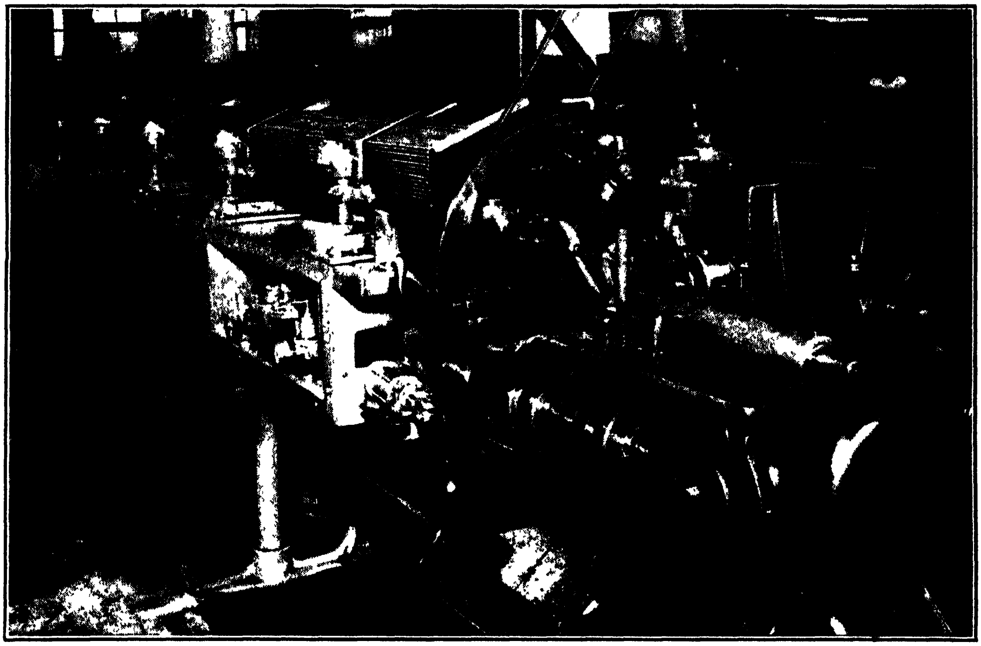


FIG. 85. *Removing material handling at the machine.* To eliminate productive time lost in manually loading bar stock into automatic screw machines, a fully automatic pneumatic bar feed has been designed which holds a normal 8-hour run of stock. The time required to load the bar feed itself or to change stock from one size to another ranges from 5 to 15 seconds. (*Courtesy of Lipe-Rollway Corporation, Syracuse, N. Y.*)

The prepositioning of tools and material for the operator is conducive to his development of a stride, or "work rhythm," which lessens fatigue by permitting a smoother sequence of motions.

Ample knee space at the workbench and good lighting for the operator are also prerequisites. For most assembly work, approximately 30 foot-candles of light are usually sufficient.

CHAPTER XI

Internal Transportation of Plant Material

1. WEIGHT, FREQUENCY, AND TRAVEL OF MATERIAL HANDLED IN A PLANT

The Chicken or the Egg

The interrelationship that exists between material handling and plant layout has a parallel in the field of economics. For years economists have been debating whether cost determines price or price determines cost in marketing a product. The question of whether plant layout determines material handling or material handling determines plant layout is likewise debatable. Unlike economists, however, engineers are prone to dismiss the moot aspects of a problem and are more inclined to settle a problem rather than argue about it for years. The fact is that an improvement made in material-handling methods usually affects the plant layout, and changes made in the layout invariably influence material-handling methods. It seems to matter but little which change comes first, so long as the end result is the same.

Definition of Material Handling

Material handling within the plant may be defined as **the transportation and movement of material, whether raw, worked, or finished, on the plant premises.**

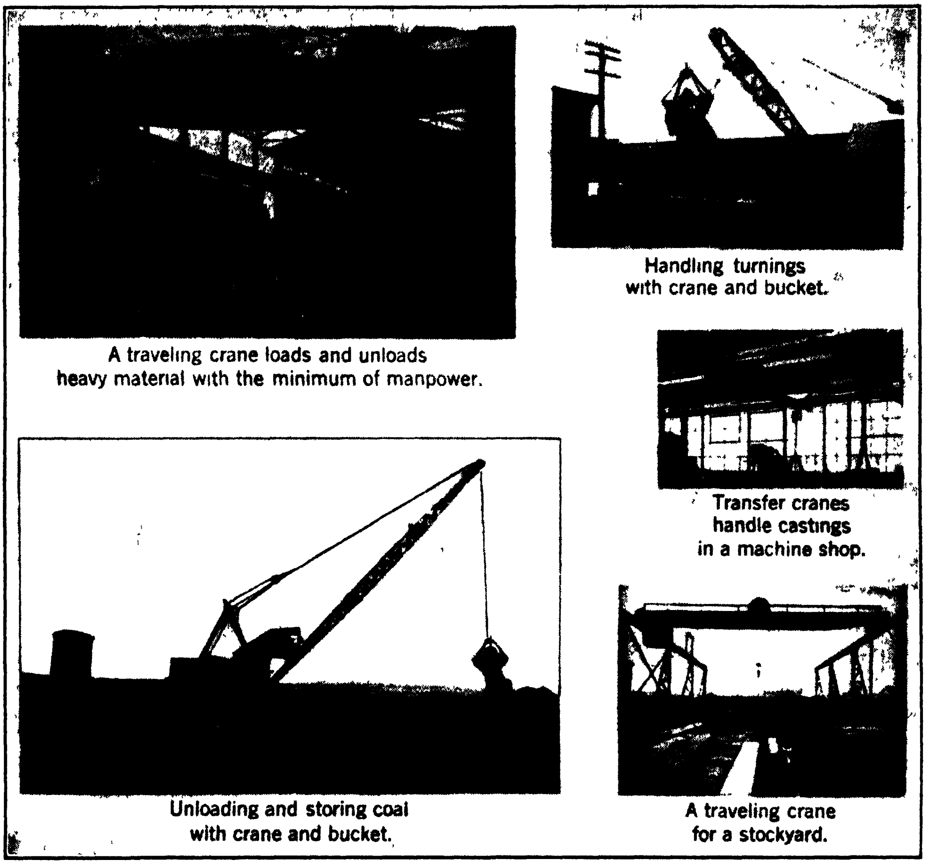
Each time the material is lifted or laid down, piled or unpiled, loaded or unloaded, transported vertically or horizontally from one position or location to another, fed into or removed from a machine, placed into or removed from storage, or moved in any way whatever, it undergoes a "handling."

Number of Handlings per Material Unit

The number of times a material unit is handled during the course of a manufacturing cycle varies with each type of unit and with each system of material handling. As many as 150 handlings are given relatively simple units in some plants.

Flow of Material through a Plant

In a representative flow, the material is first unloaded from a freight car or motor truck, placed on skids, moved by fork truck to an inspection point, unloaded for inspection, reloaded onto the skid, lifted by fork truck, trucked onto an elevator, transported to another floor, lifted by fork truck, trucked to a storeroom, unloaded from the skid, and stored into bins. It is later reloaded onto a skid, trucked to a work station, unloaded from the skid, placed on a machine, fed into the machine, removed from the machine, reloaded onto a skid, and moved to the next operation. A similar number of handlings is involved at each processing and assembling operation, inspection point, packaging point, temporary storage to await shipment, and finally on the shipping platform, when the finished product is loaded into a freight car or motor truck for outward shipment to customers.


A traveling crane loads and unloads heavy material with the minimum of manpower.

Handling turnings with crane and bucket.

Transfer cranes handle castings in a machine shop.

Unloading and storing coal with crane and bucket.

A traveling crane for a stockyard.

FIG. 86. Types of overhead and mobile cranes.

Tons Handled per Ton Shipped

For every ton of material shipped, therefore, there are many tons of material weight handled. When a product goes through 100 handlings during the course of its manufacture, roughly 100 tons of weight are handled in the plant for every ton shipped. Recent studies reveal that for every ton of finished product shipped in metal-working industries, the equivalent of 50 tons of material are handled. This ratio may be roughly ascertained for any product by making the following simple calculation. Let

A = the average number of handlings on each operation.
B = the average number of operations on each component part.
C = the number of component parts in the finished product.
D = the average weight of each component part.
E = the number of finished products manufactured.
F = the average weight of the finished product.

Then:

$$\frac{A \times B \times C \times D \times E}{E \times F} = \frac{\text{tons handled}}{\text{tons shipped}} = \text{ratio}$$

Material Handling Adds Cost with No Sales Value

When 50 tons of material weight is handled in manufacturing 1 ton of finished product, only 1 ton of this handling brings in a return in the form of sales value. This ton is the one shipped in the form of finished product. The other 49 tons handled only add cost to the 1 ton of product shipped. Material-handling operations do not change the form or otherwise convert the material in the cycle of making the finished product. These handlings occur mostly while transporting and positioning the material for processing and assembling operations.

In so far as processing and assembling are concerned, many of these handlings can be dispensed with so long as the material is found at the right place, in the right position, at the right time, and in right quantities. The planning required to fulfill these requirements is done by designing appropriate material-handling systems on the plant layout.

Plant Layout Approach to Material Handling

Until such time as material-handling problems are analyzed and solved through a thorough engineering approach and plant layouts are designed from factual information derived from this approach, many a plant will continue to handle thousands of tons of material unnecessarily each day. Throughout his planning, the plant layout engineer must keep foremost in his mind the axiom that *the time required and distance traveled in the course of manufacturing a product directly affect its cost of production.*

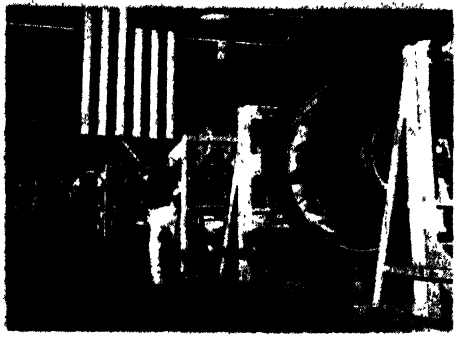
Mileage Traveled by Work in Process

The line of flow of material in processing a product runs into as many as 15 miles in some plants. It is not uncommon to shorten the line of flow by 50 or 75 percent by better material-handling planning and more adequate plant layout design.

2. TRANSPORTATION BURDEN ON OUTPUT SPEED AND COST

More Time in Handling than in Processing

In traveling through the manufacturing cycle, materials move from storage to processing operations, from one work station to another, thence through assembly and packaging, and finally into temporary storage while waiting to be



Aircraft engines move on dollies as assembly proceeds.

Thermos jugs conveyed into an overhead infrared oven, saving floor space as well as obtaining continuous-flow processing.

A symphony in tool engineering: 154 feet long, automatic operation; composed of 33 separate machines processing aircraft-engine cylinder heads.

A continuous fur dryer handling from 5,000 to 8,000 pelts per hour. Drying time cut from 24 hr. to 15 min

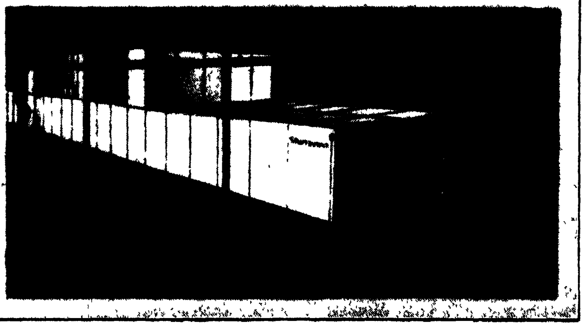


Fig. 87. Types of overhead and floor-mounted conveyors.

shipped out as finished products. It is evident from this flow that materials are in transit at many points along the processing route.

While being thus transported or placed in temporary storage during the manufacturing cycle, materials are not being processed. Studies of these movements indicate that, in traveling through a plant, materials generally are actually worked on only *one-third of the possible time,* the other two-thirds being consumed by material handling or temporary storage.

The speed of production is therefore confined to only one-third of the time that the material is flowing through process. Not until the flow of material is co-ordinated with the speed of the processing equipment can an appreciable dent be made in the two-thirds of the time now taken up by material handling and storage. By setting the pace of material handling through a well-engineered plant layout, experience in many industries, notably in the meat-packing, automobile, chemical, and food industries, has shown that the manufacturing cycle can usually be shortened to eliminate much of the two-thirds of the time the material is not being worked on.

Cost of Material Handling Not Revealed in Accounting

The amount of money being paid to skilled operators for portions of their time spent in material handling at work stations is classified as, and buried in, productive labor in cost-accounting practice. How much of this labor exists in a plant remains unknown unless special studies are made at each work station. Ordinarily much of time thus spent by skilled labor could either be eliminated through proper material-handling equipment or at least be performed by unskilled labor.

A thorough plant layout study of work stations often reveals that simple changes in the arrangement of machinery to improve material handling can produce significant savings in operating cost without investing in material-handling equipment. High-speed semi-automatic machines are frequently slowed down by such trivial matters as:

a. Improper stationing of machine operators.
b. Awkward positioning of materials, thereby occasioning unnecessary reaching.
c. Lack of co-ordination between production and shipment.
d. Irregular flow of materials brought to and taken from the machines.

Many an otherwise highly efficient machine has never demonstrated its true worth, or has failed to justify the investment made in it, because of the existence of controllable factors such as these, which a proper work-station layout would have revealed and caused to be removed. Not many people realize that all material-handling and processing operations could be mechanized to the point where labor effort could be entirely eliminated and manufacturing could be carried on exclusively by feeding the material automatically from operation to operation. In certain types of machinery, notably those for making incandescent lamps and for bottling beverages, roughly 90 percent of this goal has already been reached. This is the new science called "Automation."

FIG. 88. Applications of floor-mounted conveyors.

Portion of Payroll Spent for Material Handling

The share of the wage dollar spent by industry for material handling has been variously estimated for different industries. The figure generally used at present for all industries is 40 percent. This means that 40 percent of a plant's labor payroll is spent for material handling alone. This expenditure adds nothing to the sales value of the product, and can price some products, or even entire plants, right out of the market.

The large portion of the plant payroll incurred for material handling, and the revolutionary improvement that can be made in material-handling methods through the wide variety of material-handling equipment available today, combine to offer industry a virtually unexplored opportunity for major cost reductions. By applying sound principles of material-handling analysis and plant layout engineering, this opportunity presents a tangible challenge to the progressiveness of present-day management.

3. LAG IN EFFICIENCY BETWEEN MATERIAL HANDLING AND PROCESSING

High-Speed Processing and Antiquated Handling

Much has been written about the Industrial Revolution which was ushered in on a practical scale with the factory system around 1840. Little has ever been said, however, about the fact that processing operations have greatly outdistanced handling operations in the years that have elapsed since then. Yet, as already indicated in the preceding section, material-handling labor today accounts for roughly 40 percent of the labor payroll in American manufacturing industries in general.

In fact, the feeling is rapidly developing in many quarters that our automatic and semi-automatic machines are beginning to lose some of their superior value because of the mounting problems of transporting materials to and from these highly developed fabricating units. Scarcely a processing or assembly operation is performed today that has not been minutely time-studied in terms of man-hours expressed in four decimal places. But this searching analysis seems to have completely by-passed material-handling operations, which amount to 40 percent of a plant's wage dollar.

In analyzing manufacturing operation costs, our effort has been largely centered on such machine operations as milling, drilling, cutting, grinding, turning, finishing, stamping, etc., plus most types of assembly operations. Comparatively little thought has been given to material-handling operations, such as picking up, laying down, lifting, carrying, reaching, feeding, hauling, moving, pushing, pulling, heaving, dragging, storing, etc.

Slow Acceptance of Mechanized Handling

Engineering design of material-handling equipment over the past 50 years has not lagged behind the improvement made on processing machinery. The de-

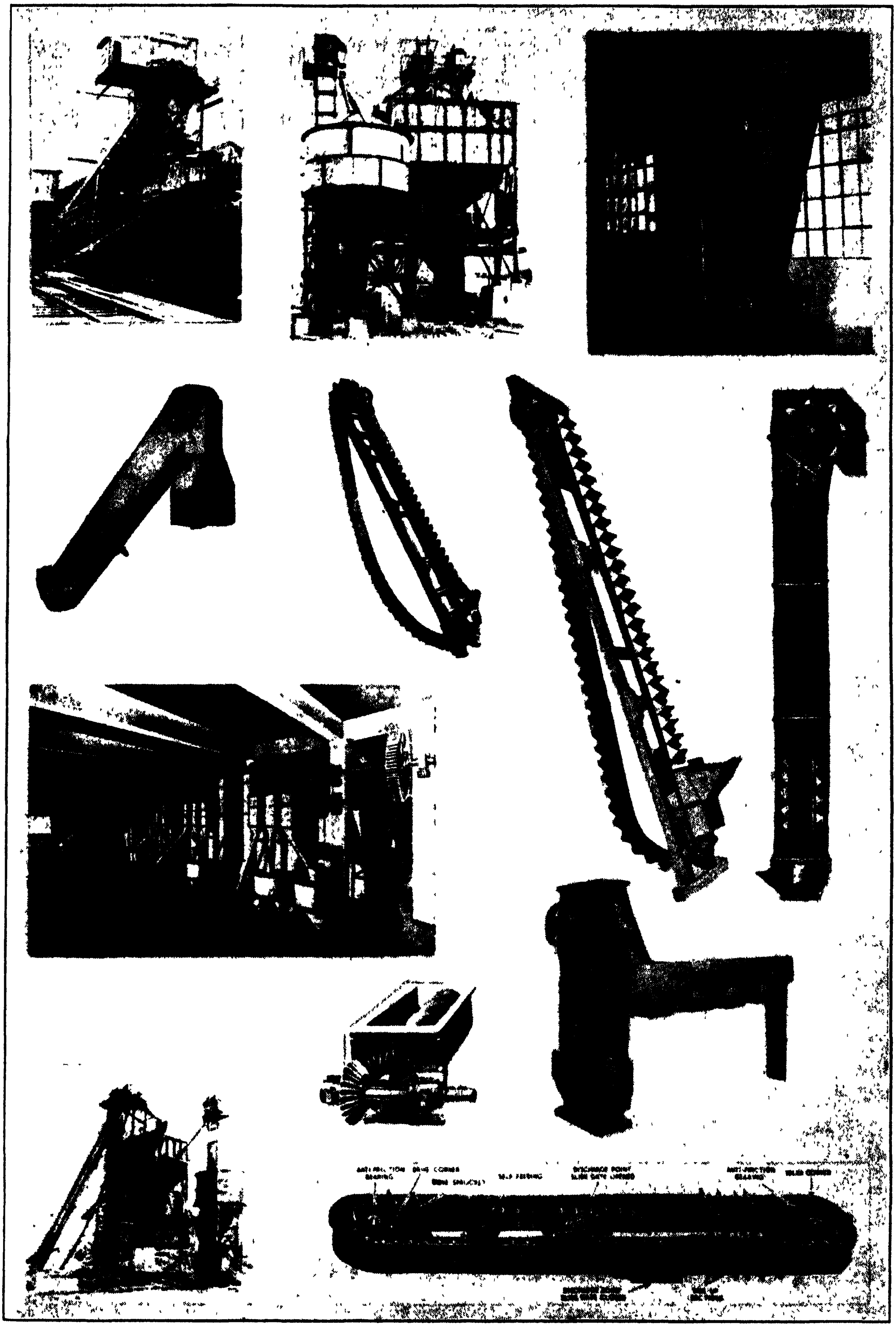


FIG. 89. Types of chain-drive and screw-drive conveyors.

ficiency in improving material-handling systems is mostly attributable to four basic weaknesses in industry's modernization programs before World War II:

a. Unfamiliarity with the material-handling equipment available.
b. Lack of proper application of such equipment.
c. Failure to properly design the plant layout to permit this equipment to actually reduce or eliminate material-handling operations.
d. Neglect to mechanize the material-handling operations (through the use of modern material-handling equipment) remaining after eliminating the unnecessary ones.

Modernized Handling of War Production

The unprecedented production demands of World War II awakened the collective mind of manufacturing industry to the hitherto unrecognized importance of material-handling improvements in reducing costs and increasing the efficiency of production. Before that time, industry had been buying material-handling equipment on the basis of what today would be considered vague and arbitrary recommendations. Engineers and shop supervisors would simply request that cranes be installed for this or that job, a conveyor placed here, a hoist there, lift trucks purchased for this work, or a chute for that work.

Little, if any, attempt was made to appraise these recommendations in terms of specific measurements of the amount of material-handling work involved, and for what duration. Nor was a sound comparison made of operating costs and relative savings under the different types of handling which could perform the task for which the equipment was recommended. This haphazard, piecemeal approach to material-handling problems has caused the hidden opportunities for reducing operating costs to be generally overlooked.

4. CLASSIFICATION AND APPLICATION OF MATERIAL-HANDLING EQUIPMENT

Extent of Mechanization of Handling

For the purpose of reducing the rising cost of handling material and of expediting the flow of material through the successive stages of manufacturing, various mechanical devices have been developed since 1920. A variety of some 300 major mechanical handling devices are on the market, and many of them have overlapping applications.

It is not always necessary to mechanize a handling operation in order to reduce costs. Often a well-planned rearrangement of the plant layout uncovers savings which may be realized without investing in handling equipment. There is such a thing as overconveyorizing a plant or of overequipping a plant to the point where the equipment requires more maintenance cost than was saved in handling cost. Such situations have developed in some plants largely as the result of the lack of a proper layout design, or of arbitrary decisions made under force of circumstances, or of high-power salesmanship by irresponsible equipment suppliers' representatives.

Classification of Material-Handling Devices

The various kinds of material-handling devices may be classified into four broad categories according to the mobility of the equipment: (*a*) either mobile or fixed, (*b*) mobile, (*c*) fixed, and (*d*) miscellaneous.

Major Groups of Equipment

Each category is generally subdivided into major groups, of which there is a total of 12:

THE 12 MAJOR GROUPS OF MATERIAL-HANDLING EQUIPMENT

A. **Either mobile or fixed**
  1. Cranes
  2. Conveyors

B. **Mobile**
  3. Tractors and trailers
  4. Trucks, skids, and pallets
  5. Railroad equipment
  6. Tiering machines

C. **Fixed**
  7. Lifts and hoists
  8. Monorail systems
  9. Pneumatic systems
  10. Chutes

D. **Miscellaneous**
  11. Industrial storage facilities
  12. Process-handling equipment

Types of Devices

Each of the 12 major groups is in turn broken down into component types of devices in Table 5. For example, there are 11 types of cranes, 8 types of conveyors, and 5 types of tractors and trailers. In all, there are 75 recognized types.

A further refinement of the 75 types is made, also in Table 5, in terms of different items of equipment. The total of these items amounts to 300.

As an example of the classification employed in the table, let us examine major group 1—CRANES. The table classifies cranes into 11 types as follows:

1. Overhead bridge, traveling.
2. Overhead bridge, non-traveling.
3. Gantry, traveling.
4. Gantry, fixed.
5. Jib.
6. Pillar.
7. Locomotive (crane).
8. Derrick (crane).
9. Special (crane).
10. Cableways, suspension.
11. Cableways, tramway.

The table then subdivides each type into its different items of equipment. For example, Type 3, Gantry Traveling Cranes, are subclassified into the following 4 different items:

1. Portal.
2. Semi-portal.
3. Portable.
4. Folding jib.

Photographic illustrations of some of the different items of material-handling equipment are given in the following 6 figures:

Figure 86. Types of overhead and mobile cranes.
Figure 87. Types of overhead and floor-mounted conveyors.

TABLE 5. CLASSIFICATION OF MATERIAL-HANDLING EQUIPMENT

A. EITHER MOBILE OR FIXED GROUP				*B*. MOBILE GROUP							
1. Cranes		2. Conveyors		3. Tractors and Trailers		4. Trucks (Skids and Pallets)		5. Railroad Equipment		6. Tiering Machines	
Type	Item	Type	Item	Type	Item	Type	Item	Type	Item	Type	Item
Overhead bridge, traveling	Power, cab drive Manual, chain drive Push type Weigh larry Traveling platform	Roller, gravity	Spiral Portable Roller (plain) "V" trough Double-deck	Tractor, road	Crawler Road tractor Half tracks Trencher Excavator Grader Shovel Drag-line Roller Crusher Sweeper Bucket	Road, motor transport	Crawler Van Commercial Dump body Elevated ladder tower Spreader Crane mount Tank	Engine, types	Electric Steam Diesel Fireless Trolley Switch	Fixed frame, portable	2-post, manual 4-post, manual Revolving base 2- and 4-post, power
Overhead bridge, non-traveling		Roller, live	Gear Chain Belt Push bar Magnet	Trailer, road	Semi-trailer 4-wheel trailer Low platform Pole-type bolster Track-laying Mobile loading platform Pump Grader	Industrial hand, manual operation	Platform (push) Hand lift (for skids) Barrel (2-wheel) Stevedore (2-wheel) Box (low frame) Pallet lift (pull) Scale truck Dolly Gear type Super-structures Reel truck Carboy truck	Cars, standard gage	Box Condola Flat Tank Hopper Pot Car dumper	Telescopic frame, portable	2-post, manual 4-post, manual 2- and 4-post, power Suspended
Gantry, traveling	Portal Semi-portal Portable Folding jib	Wheel	Wheel Portable Disk Cable drive	Tractor, industrial	3-wheel 4-wheel Trailer train Pusher method			Cars, narrow gage	Side dump (automatic) Side dump (manual) Air dump	Special	
Gantry, fixed	Tower Whirler	Belt	Portable Troughed Piler Flat Feeders Metal Tower and track					Trackage	Rails Ties Gages Switches Frogs Turntables		
Jib	Column, rotary Wall bracket Pillar jib Portable Bracing types Walking jib Wall-traveling Folding jib	Drag	Pusher bar Rotary Screw Flight					Special			

Pillar	**Straight boom** **Curved boom**		En masse Floor chain buggy Chain Drag scraper Chain dig loader Washer (screw)	Trailer, industrial	Caster steer Fifth-wheel steer Four-wheel steer Side dump Bolster Stevedore Tool wagon	Industrial hand, power drive	Pallet Platform			
Locomotive	**Flatcar mount** **Crawler mount** **Truck mount** **Floating** **Pile-driving** **Wharf** **Wrecking** **Drag-line** **Magnet** **Bucket types**					Industrial power, non-lift type	Low platform High platform			
		Apron	**Wood slat** **Steel slat** Carrier chain Steel pan Feeder	Special	Marine tractor	Industrial power, lift type	Low lift platform High lift platform Telescopic platform Non-telescopic fork Telescopic fork Ram-telescopic Platform crane Manual steer-platform lift			
Derrick	**Sulky** **Stiff-leg** **Guyed type** **Pole type(gin)** **Tower** **Portable** **Breast** **"A" type**	**Bucket**	Peck conveyor							
		Ball and caster, transfer	Ball transfer Caster transfer							
Special	**Tower crane** **Floating crane** **Wharf—gantry** **Gantry—locomotive** **Transfer** **Cantilever** **Hammerhead** **Safety codes**					Power, road or industrial, and special types	Straddle Rigid boom Swinging boom Dumpster			
Cableways, suspension	**Endless cable** **Single cable** **Telpher**									
Cableways, tramway	**Overhead** **Surface** **Inclined plane**									

TABLE 5. CLASSIFICATION OF MATERIAL-HANDLING EQUIPMENT—*Continued*

C. FIXED GROUP								*D.* MISCELLANEOUS GROUP			
7. Lifts and Hoists		8. Monorail Systems		9. Pneumatic Systems		10. Chutes		11. Industrial Storage Facilities		12. Process Handling	
Type	Item	Type	Item	Type	Item	Type	Item	Type	Item	Type	Item
Elevator, freight	Electric Hand power Hydraulic Pneumatic	Carrier	Monorail carrier	Tube, rigid	Bulk conveyor Unit conveyor Portable Bulk transport	Spiral	Curved chute Closed center Open center post Open center	Bins and boxes	Storage bins Assembly bins Portable bins and boxes Box frames	Balers and binders	
Elevator, passenger	Electric Hydraulic Hand power Pneumatic	Trolley	Monorail trolley	Pipe and hose, rigid and flexible	Bulk loader Bulk unloader	Straight	Steel and wood Canvas Skid Rail Vibrating Gates Discharge (Conveyor)	Benches	Work	Dereelers	
Elevator, dumb-waiter	Electric Hand power	Chain	Chain buggy Chain trolley Enclosed chain Pusher	Special	Vacuum systems Blast systems Portable compressor	Sluices and flumes, waterforce	Wood Metal Pipe Open	Ladders and scaffolds	Straight-rung Step Wheeled-base	Stitchers and pasters	
Elevator, short rise; sidewalk or floor	Electric Hydraulic Hand power Pneumatic	Telpher	Monorail telpher Cable telpher Automatic			Special		Lockers and cabinets	Clothes Tools Supply	Positioners	
Electric stairway	Passenger Freight	Special						Racks	Bar Barrel Tree Portable	Special	
Hoists, reciprocative	Skip hoist Automatic Semi-automatic Portable elevator Lowerer							Bunkers			
								Shelving and drawers	Open Closed Roller Unit		
								Tables	Inspection Work		

Lifts, continuous	**Chain mount** **Belt mount** **Fixed tray** **Swing tray** **Single-chain** **Bucket**								**Laydown** **Machine tender** **Die table** **Lift table**	
Hoist units	**Chain (portable)** **Electric** **Winch (portable)** **Capstan** **Windlass** **Ratchet puller** **Steam hoist** **Pneumatic** **Air trolley**							Tool containers	**Portable, fixed** **Portable, rotary** **Tool rack** **Die rack**	
								Tote pans	**Metal** **Wood** **Fiber**	
								Pallets and trays	**Assembly pallets** **Assembly trays** **Tool trays** **Storage**	
								Special		

Figure 88. Applications of floor-mounted conveyors.
Figure 89. Types of chain-drive and screw-drive conveyors.
Figure 90. Types of tractor-and-trailer trains.
Figure 91. Types of skids, lift trucks, and tiering machines.

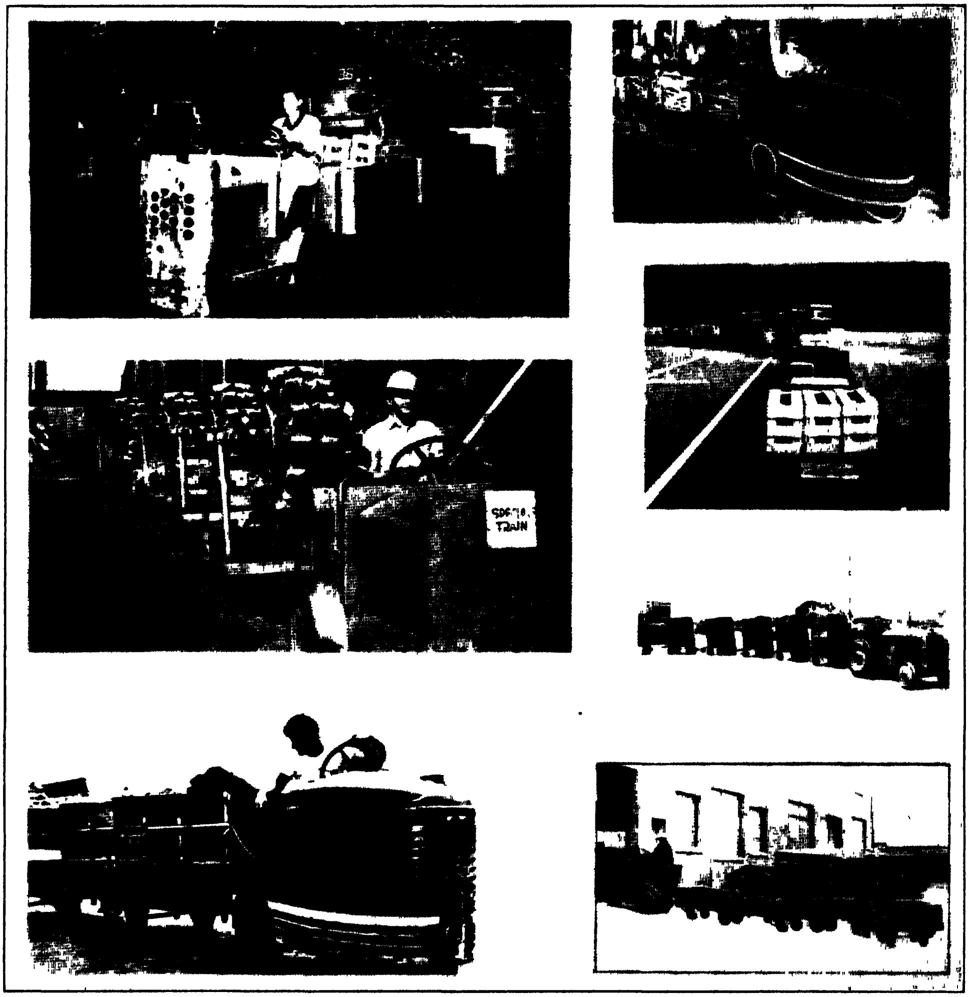


FIG. 90 Types of tractor-and-trailer trains.

The information in the table has been compiled with the assistance of technical advisers of the Westinghouse Electric Corporation, representatives of various industries, publishers of trade magazines, manufacturers of material-handling equipment, manufacturers' national associations, and various engineering societies. With such information at hand, an opportunity is provided the plant layout engineer to take a bird's-eye view over the whole field of material-handling equipment from which to make a tentative selection of the various devices applicable to the job under consideration. Out of this tentative selection will emerge the "one best" device for the particular plant layout being developed.

The final selection of the "one best" device, however, is not made until all the cost and performance factors surrounding the given application have been thoroughly evaluated. This analysis constitutes the only positive approach to the proper planning and selection of material-handling systems.

5. FACTORS CONSIDERED BEFORE RESORTING TO MATERIAL-HANDLING DEVICES

Material Handling by Machine Operators

When the total cost of material handling becomes known in a plant, a change in layout usually follows. In this cost must be included not only the transportation of material from one location or operation to another but also the handling done by each operator at a work station.

In most processing and assembly operations, the operators must handle material. They pick it up or lay it down, feed it into the machine or assembly unit, remove it from the machine, etc. The extent of handling by the operators is dependent largely upon the layout of the work station and the plant layout of the adjacent areas. The cost of this handling is not revealed in cost accounting and must be ascertained by observation or time study.

How the Investment Pays for Itself

The plant layout change that usually follows upon learning the total cost of material handling inevitably calls for investing money for material-handling devices. Investing, for example, $50,000 to save $50,000 in operating cost over two years, or at the rate of $25,000 a year, increases net profit by $25,000 a year for each year beyond the initial two years. When the investment thus pays for itself in two or three years of operations, after which it begins to yield an increase in yearly net income for the years that follow, the size of the amount so invested, be it $50,000 or $500,000, so long as it can be funded, is not so speculative as it might appear. That amount of money will be spent anyway. It will either be lost forever in the form of excessive material-handling costs charged to operations, or it will be saved and invested in the purchase of equipment that will not only pay for itself but afterwards increase the net income.

In recommending a new material-handling system, however, note must be taken of the fact that *simplified* handling is not necessarily conducive to *economical* handling. The operating characteristics of the equipment as applied to the task to be performed constitute but one of two major factors to consider in selecting the most suitable material-handling method. The other major factor is the amount of investment to be made for the equipment and the period over which this investment can justifiably be amortized.

For example, in choosing between trucks and conveyors for a job that is not expected to last more than a year or two, the fixed-conveyor system would have to pay for itself entirely within the first or second year. The trucks, on the other hand, could be used for other purposes at the end of that period and could thus be amortized over their full operating life. In this case, even though the handling would be more greatly *simplified* by using conveyors, it is more *economical* to use trucks.

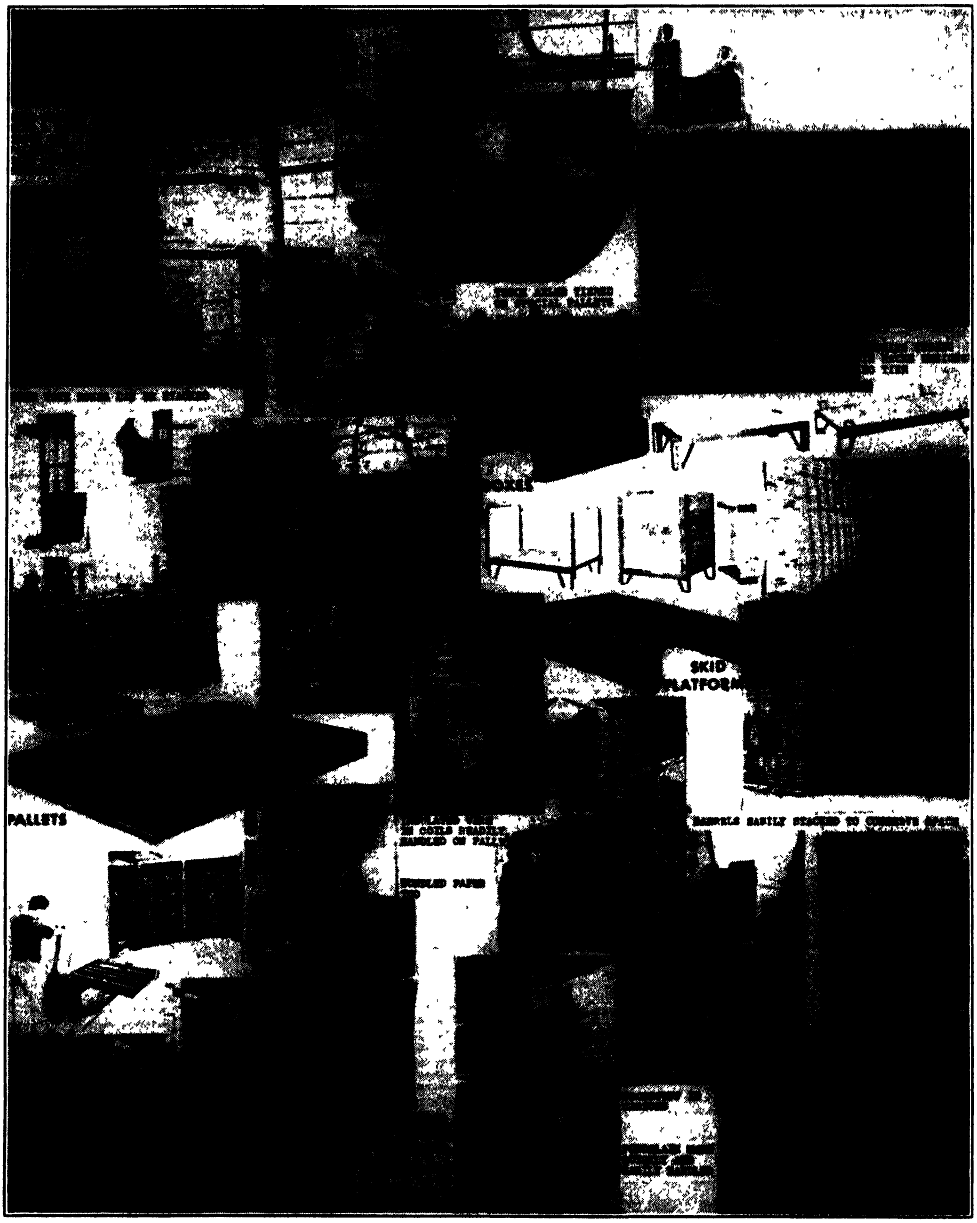


Fig. 91. Types of skids, lift trucks, and tiering machines.

Estimated Savings and Hidden Added Costs of a Project

The president of a national manufacturing company once stated that if all the estimated savings projected in the appropriations approved in his company over a period of ten years were to materialize actually, that figure would be enough to retire all the employees on a comfortable income for life. This situation is far from unique. On the contrary, it may be considered as being typical of what goes on continually in many progressive concerns.

The general tendency, which is also a natural one, to stress the savings angle often eclipses the hidden added costs, such as increased fixed charges, ill-timed obsolescence, and unforeseen changes in processes. A sound approach to the problem of selecting the most suitable material-handling system for a plant layout must therefore take into consideration not only the engineering aspects of the handling but also the entire economic appraisal of the various material-handling systems that lend themselves to the job to be performed.

Eliminating Handling before Buying Devices

Before undertaking the selection of material-handling devices for a plant layout, a number of corrective measures in the processing operations themselves need to be explored thoroughly. This initial approach consists primarily of analyzing the processing operations for the purpose of reducing the material-handling problem to a minimum before resorting to the purchase of mechanical devices. In other words, many material-handling operations can be reduced or eliminated before seeking a solution in the field of material-handling devices.

Corrective Measures Which Eliminate Handling

The common points to analyze and correct before thinking about material-handling equipment are the following:

a. **Number of operations.** A reduction in the number of processing operations will reduce the number of handlings in direct proportion.

b. **Sequence of operations.** By changing the sequence of processing operations, the number of handlings and the distance traveled may often be materially reduced.

c. **Combination of parts.** By combining component parts into a new part of greater size and weight, there will be fewer parts to be handled, and the number of handlings will be reduced commensurately.

d. **Redesign of tools and dies.** By redesigning the dies, the number of punching and forming operations may be reduced. As indicated in point *a*, this will reduce the number of handlings in direct proportion. Moreover, a reduction in the number of die operations means less machine setups and more productive time available on the machinery.

e. **Redesign of the product.** A change in the design of the product may facilitate material handling in the following respects:

1 Changing from *fragile* to sturdier material may speed up the handling.
2. Reducing the *thickness* of the material would lighten the loads to be handled.
3. Changing to a tougher *finish* will reduce the need for unusual care in handling.

Having considered these factors, and thereby reduced the number of handlings and the length of distance traveled to the lowest degree compatible with sound processing practice, an analysis may now be made of the remaining material-handling requirements. In making this analysis, not only are the operation characteristics of the various material-handling devices compared, but also the operating and maintenance costs of each type of equipment that is considered for the job.

CHAPTER XII

Planning the Material-Handling Project

1. ANALYZING THE MATERIAL-HANDLING REQUIREMENTS FOR A LAYOUT

Selecting the Handling System

To plan the type of material-handling system which will come nearest to being the most suitable, practical, and economical plan, a definite set of contributory factors must be examined and co-ordinated. Many of these factors are often overlooked or blindly bypassed, with the result that recommendations are based largely on superficial observations. A scientific analysis of a material-handling problem usually reveals the fallacies contained in superficial conclusions.

For example, a recommendation that a conveyor be placed in a certain location, without analyzing the frequency and permanence of the use to be made of this conveyor, does not take into account the possibility of greater over-all benefits which may be derived from using equipment of greater mobility and flexibility, such as industrial trucks. For these and other reasons to be explored in the present chapter, the facts underlying a material-handling operation, or cycle of operations, must be analyzed and co-ordinated as accurately as is done with the data that determine machine loads and processing sequence.

Material Handling and Plant Layout

It is generally recognized that all the factors that affect material handling are fundamentally concerned with plant layout. Needless handling operations can frequently be eliminated when the movement of materials is carefully studied for the purpose of tying in the material-handling operations with the layout of the production floor. This leads particularly to the elimination of "bottlenecks," that is, places where production tends to slow down because of the piling up of materials in process.

When material handling is studied in relation to the layout of the plant as a whole, potential bottlenecks are minimized. The first step in the analysis of any material-handling project must therefore always be a consideration of the flow of material through the various processing operations. In practically every instance, the solution of the material-handling problem requires the relocation of some of the existing facilities, and the corresponding rearrangement of the plant layout.

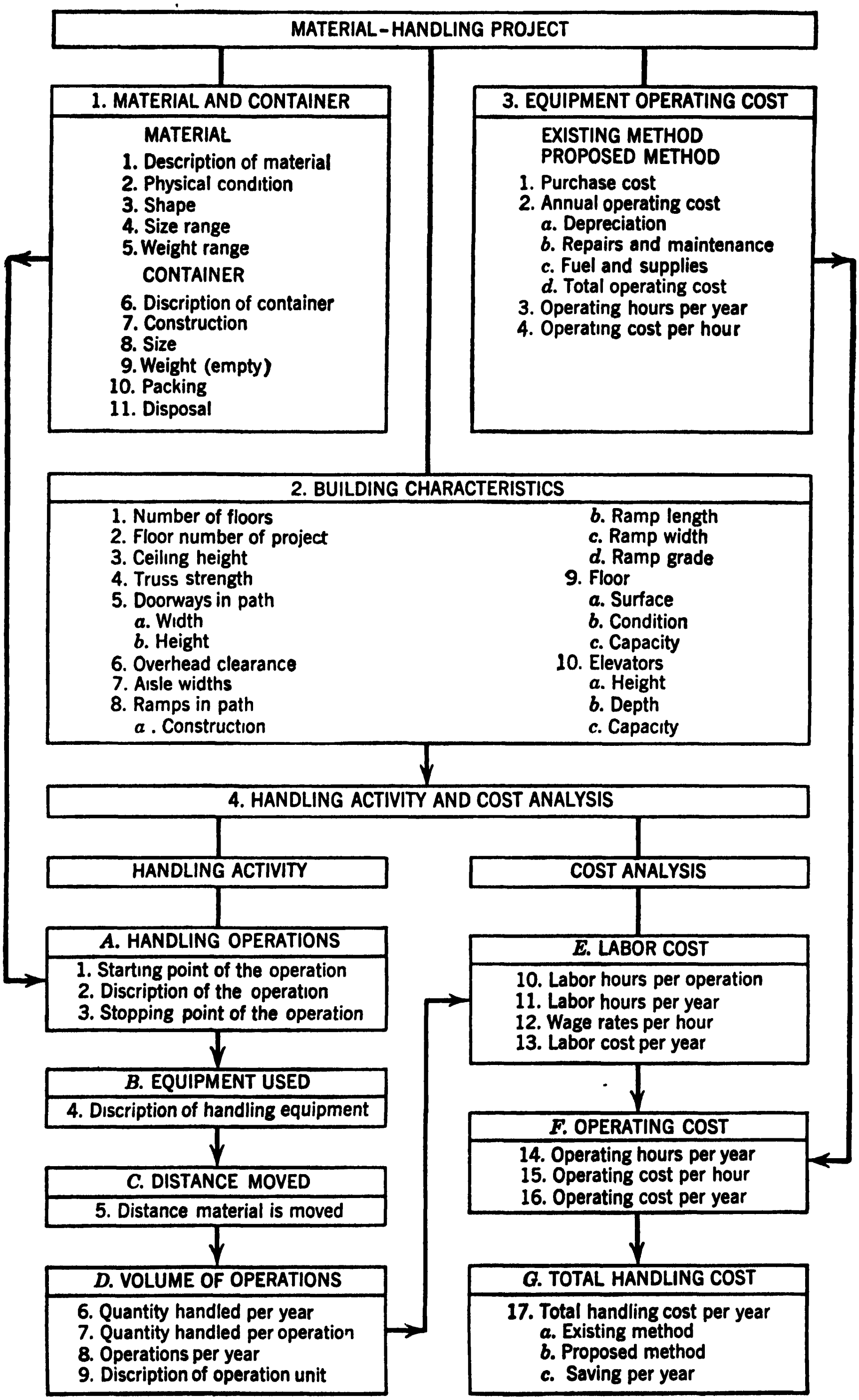


FIG. 92. *Check-list of data* required for a material-handling project.

Integration of Component Parts and Separate Handlings

Most problems of handling usually involve more than one material item and more than one handling for each item. Material items are rarely received, processed, stored, and shipped out in a continuous flow or on the same day. Some material items are received in large quantities, stored, and later processed in smaller quantities. Others are received and processed the same day and are then placed in storage to await assembly or shipment.

Integrating the elements of a given production line into a final assembled unit is an engineering problem of the highest order. Planning the handling of material through the flow of production is inseparably dependent on the arrangement of the plant layout. The layout must therefore take into account the work-simplification techniques not only of processing and assembly operations but also of material-handling operations.

Check List of Material-Handling Factors

A check list of the various factors that generally enter into the development of most material-handling projects in industrial plants and commercial warehouses is contained in the chart shown in Figure 92. Specific industries may add special factors here and there which appertain particularly to their problems, but none of the factors outlined in the chart can be left out without sacrificing the quality and applicability of the analysis. A glimpse of the scope of material-handling problems involved in modernizing a refractories plant is provided in Figures 93 and 94. The four main categories of factors listed on the chart are: (1) material and container; (2) building characteristics; (3) equipment operating cost; and (4) handling activity and cost analysis.

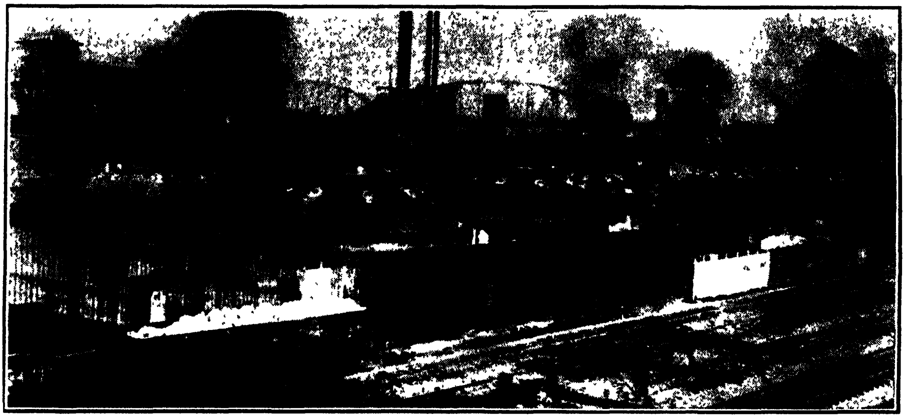


FIG. 93. *Scope of material-handling projects* in modernizing a plant is illustrated here with the outside view of an old-style brick plant, as contrasted with the aerial view in Figure 94 of a modern refractories plant. (*Courtesy of Harbison-Walker Refractories Company.*)

These factors are discussed in detail in the following four sections which make up the remainder of the present chapter: physical aspects of the material and

its container; building characteristics and safety factors; fitting the equipment operations to the volume of activity; and labor cost, equipment operating cost, and net benefits.

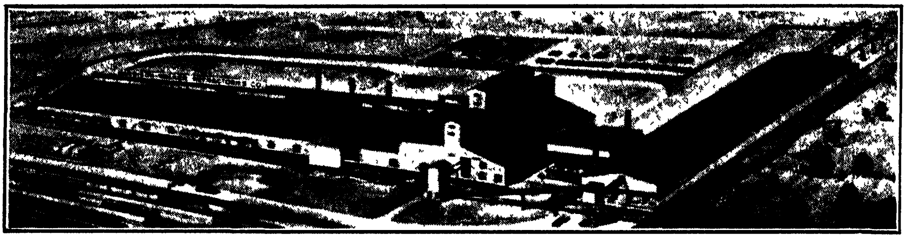


FIG. 94. *Modern refractories plant.* Practically all processes are housed in one building. Raw material is received in hopper cars on railroad siding, crushed as received, and conveyed to many separate piles in raw storage building on the right. The material is reclaimed by scoop trucks and delivered by belt conveyors into bins in high part of main building. It is then ground to required fineness, screened, mixed, pressed, and set directly on tunnel kiln cars at the presses. The material then passes on the kiln cars through driers and tunnel kilns, at a temperature of from 2000° to 3000° F. (*Courtesy of Harbison-Walker Refractories Company.*)

2. PHYSICAL ASPECTS OF THE MATERIAL AND ITS CONTAINER

Variety of Physical Aspects

In any material-handling project, the first things to be considered are the physical aspects of the material itself, such as fragility, corrosive and combustible qualities, shape, size, weight, and whether in a solid or liquid state. This involves consideration of whether the material is to be moved en masse or by individual units, such as a piece part or a subassembly, or whether the material is to be placed in containers, such as tote pans, kegs, pallets, or skids. The care and condition required for the material, such as temperature, humidity, and shock, are also factors to be studied at the outset. Processing operations, such as drying, shaping, and hardening, may be performed during the transportation of the material.

Case Analysis for Handling Steel Tanks

To illustrate the type of data called for under heading 1, Material and Container, in the check list of Figure 92, let us take the following actual example:

1. MATERIAL AND CONTAINER

Description of material:	Steel tanks
Physical condition:	Painted
Shape:	Basically round
Size range:	12 inches dia. × 24 inches long, to 22 inches dia. × 42 inches long
Weight range:	20 to 130 pounds
Description of container:	Pallet

Construction of container: Wood
Size of container: 48 inches × 48 inches
Weight of empty container: 180 pounds
Container packing: 7 tanks (average)
Disposal of empty containers: Returned on caster trucks

Description of material. Only a general description of the kind of material. This could be canned goods, bottled goods, castings, wire, eggs, hay, flour, cloth, paper, tar, acid, tobacco, ingots, bar stock, sheet stock, frames, motors, hatch covers, tires, etc.

Physical condition of the material covers such physical attributes as liquid, molten, frozen, perishable, granular, wet, inflammable, powdered, explosive, fragile, and hot.

Shape of material, such as bar, sheet, round, cubical, bundle, bunch, roll, reel, and bulk.

Size of a material unit is expressed in such terms as pipe lengths, roll sizes, reel sizes, box dimensions, board lengths, bulk granules, bulk liquid, and continuous length.

Weight range of individual material units or piece parts, whether handled singly or in containers. Weight is expressed in tons, pounds, or ounces, depending upon the relative size of the material unit.

Description of container is expressed in brief terms, such as bale, bag, bolt, ream, roll, crate, box, pallet, skid, carton, roll, reel, keg, and barrel.

Construction, size, and weight of container are self-explanatory.

Container packing means simply the number of material units or pieces held or carried in one container, such as pallet of 7 tanks, carton of 24 cans, keg of 100 pounds, and reel of 500 feet.

Disposal of empty containers is indicated in order that proper provision be made in the plant layout for the handling of empty containers at the termination of each material-handling or manufacturing cycle.

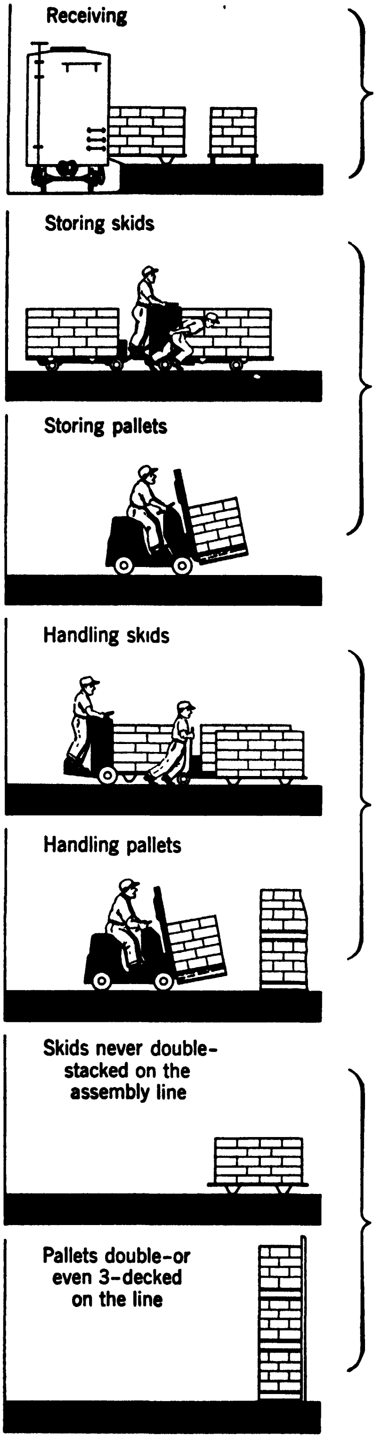
Handling of Empty Containers

The first basic decision with regard to the handling of individual items concerns the container in which the material is moved. If new containers are needed, consideration must be given to the facilities for storing these containers between production operations. The containers must therefore lend themselves to tiering and inexpensive return transportation to the starting point. Other considerations given the containers are as follows:

a. Are the containers too large or too heavy?
b. Do the containers necessitate manual removal of material in order to empty them into hoppers?
c. Could the vendor's containers be changed in size or design to facilitate material handling?

Skids and Pallets

Material can often be moved more easily and quickly if placed on skids or pallets or in unit loads, as illustrated in Figure 95 for grocery merchandise in wholesale warehouses. The illustrations in this figure compare the different ways of handling skids and pallets in receiving, hauling, storing, and distributing grocery merchandise in a warehouse.


Receiving
Storing skids
Storing pallets
Handling skids
Handling pallets
Skids never double-stacked on the assembly line
Pallets double-or even 3-decked on the line

1. Receiving Goods

Skids are taken into the car or dray and loaded with as many as 100 cases of goods. This process differs with pallets only in that pallets are usually smaller, hold less, and therefore more of them are needed for a drayload or carlot of incoming merchandise.

2. Hauling to Storage

With either skids or pallets, the load is hauled to storage or to the assembly line, but when skids are used, the hauling is sometimes done by men using manual jacks. In some instances the hauling is done by automotive lifts, as in chain-store warehouses. The streamliners use either skids or pallets and handle them with such automotive machines as platform lifts or fork trucks. These machines do the hauling, and, in the case of high-lift platforms or fork trucks, they do the lifting too.

3. Stacking in Storage

With either skids or pallets, the goods are then stored or placed on the assembly line. Skids are sometimes high-stacked in the reserves but never on the assembly line. Thus the job of replenishing the line is finished when the jack or machine places the skid on the floor. But with pallets there is always high-tiering, both on the line and in the reserves, and pallets can only be handled by a fork lift in such work. But if the haul is long and the aggregate tonnage is large, the fork may be supplemented by a tractor-trailer train for the hauling.

4. Feeding Assembly Lines

When goods are placed on the floor on skid-type assembly lines, the skids are set directly on the floor, and no great part of the cubage of the warehouse is used, nor can it be, for the wholesaler does not want an oversupply of any item on the line to increase its length, thus increasing the cost of the minimum order-picking walk. But with pallets the goods are placed on one of three levels. The two lower levels may be active stocks, or the two upper may be storage stocks. Storage on the line is an advantage with pallets and a disadvantage with skids.

FIG. 95. *Uses made of skids and pallets* in wholesale grocery warehouses. (*U.S. Dept. of Commerce, Industrial Series No.* 18.)

3. BUILDING CHARACTERISTICS AND SAFETY FACTORS

Drawings

When a request for a material-handling analysis is received, the first thing the plant layout engineer does is to obtain drawings showing the building construction. These are needed for an understanding of the characteristics of the building that houses the operations being performed. When multiple building operations are involved, the plot plan is also obtained. This gives the engineer a perspective of the relative location of the various buildings.

It is also necessary to obtain a reasonably exact plant layout drawing showing the relative position of the various production operations and the flow of the product from operation to operation. A study of this layout will bring out the geographical aspects of the problem. When studied in conjunction with the building construction drawings, the layout provides the engineer with a full conception of the physical scope of the problem.

Building Characteristics

In conjunction with these plans, the plant layout engineer must also obtain data on building elevation, ceiling heights, column spacing, structural strength, door openings and clearances, aisles, ramps, floor-load capacities, elevator capacities, location of service facilities (communications, water, electric power, and lighting conduits), location of ducts, and process characteristics that might influence his recommendations. For much of this information, the plant layout engineer must rely on his practical experience in plant layout and on his knowledge of material-handling systems.

Before attempting to select any single piece, or combination of pieces, of material-handling equipment to do a particular job, these building characteristics must be analyzed in relation to each other. The most economical equipment, from the standpoints of labor cost and operating cost, may be priced out of consideration by the capital investment in building alterations required to permit the use of the equipment.

Traffic Hazards

Whether he is analyzing the loading platform, production area, or warehouse space, the engineer must know about the doorways and elevators. Consideration must be given to separate entrances for pedestrians and trucks. Automatic doors for the opening and closing of truck entrances help greatly in eliminating hazards. Elevation of track siding with respect to unloading platforms, a minimum number of railroad crossings, and adequate facilities for moving freight cars are other points to be noted. Truck traffic may be greatly reduced by locating storerooms and material depots close to building entrances.

The height of a conveyor should be arranged so that the material can be placed on the conveyor without reaching or straining. When practical, vertical curves in monorails or inclines or declines in roller-bed conveyors are helpful to bring loads to bench height or floor level. Adequate crossovers, hinge-type gates, etc., for roller conveyors should be studied. Guards should also be placed under overhead conveyors to protect the workers below against injury from falling loads.

Aisles

Main aisles should be laid out first to insure traffic access from one building to another and also within the building. If this is not done before the actual layout is begun, difficulty may be encountered in doing so later. In order that work can move properly through the factory, adequate aisle space must be provided. From the standpoint of efficiency and safety, aisles should be laid out as carefully as the placement of the machine tools. The increase in speed and volume that has accompanied the material movement needed in mass production has made the planning of aisles a major function of plant layout engineering. Some of the most important points to keep in mind when laying out factory traffic aisles are the following:

a. Wherever possible, aisles should be used for **one-way traffic** and should be at least 2 feet wider than the widest vehicle to be accommodated.
b. When aisles are to be used for **two-way traffic,** they should be at least 3 feet wider than the combined width of two vehicles.
c. **Pedestrian traffic** should be separated from vehicular traffic as much as possible. When both types of traffic are inevitable in the same aisle, provision must be made in the width of the aisle for pedestrians to keep out of the way of approaching vehicles.
d. The layout should be planned for the movement of all materials continuously in one direction in order to eliminate **cross-traffic** in the aisles.

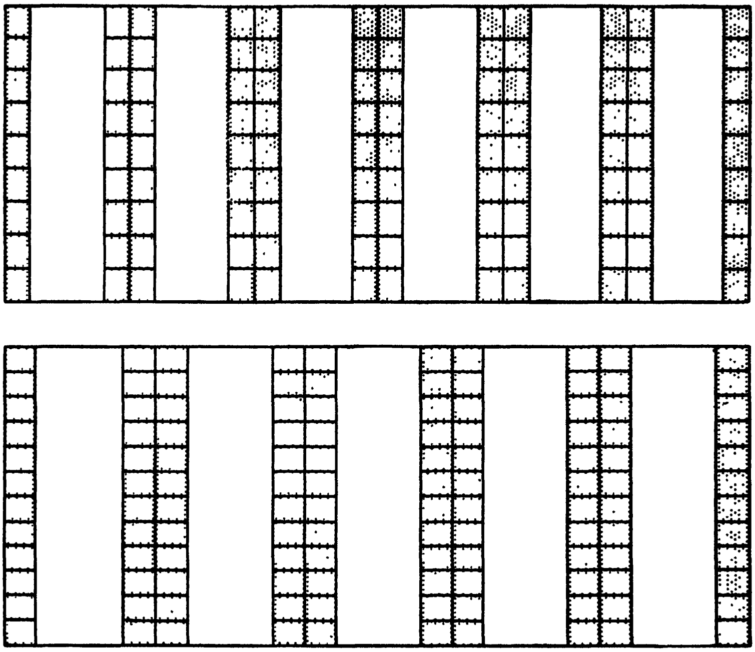
Floor Space

In the past, many a company built new additions to a plant to get needed additional floor space before very much thought was given to the possibilities of "air rights," or unused overhead space, by using *vertical* space-stacking systems. By taking advantage of vertical space in the plant or warehouse for stacking materials on pallets, the addition of a bay or of a new wing is often rendered unnecessary. Following this idea even further, it becomes evident that neat, compact stacking is conducive to keeping better inventory controls over raw materials, working material, and finished products.

Modern material-handling devices, such as pallets and fork trucks, make possible drastic reductions in the time and cost of moving material. This is accomplished by moving large "unit loads" instead of single pieces or product units. The floor layout of pallet loads must be as carefully planned as the layout of machinery, if floor space is to be conserved. In Figure 96, the same floor area is made to accommodate 120 pallet loads instead of only 108 by simply rearranging the alignment of the pallets on the floor. In Figure 97, a comparison is made of the efficiency of space use by stacking pallets at **right angles** and **diagonally** to the building walls.

Safety Standards

Although the primary purpose of a mechanical-handling system is usually to increase the efficiency of production flow, the system incidentally serves to lessen the possibilities of personal injuries by reducing, or completely eliminating, manual handling. Mechanical handling thus tends to lower the accident ratio by reducing the number of times the manual handler is exposed to hazards.



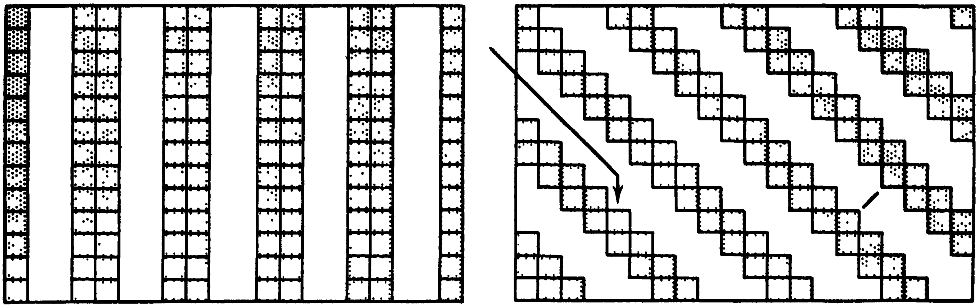
In the upper drawing, the area of 90 × 36 feet permits the use of 9-foot aisles and the placement of 108 3 × 4 foot pallets on the floor, when the pallets are arranged so that the greater dimension faces the order picker (the aisle). In the lower sketch it will be seen that the area has 10-foot aisles, but that with the smaller dimension of the pallet facing the aisle, 120 pallets of the 3 × 4 foot size are accommodated on the floor. As a result:

	Upper Drawing	Lower Drawing
Number of square feet in the area	3,240	3,240
Area of the aisles, feet	1,944	1,800
Percent of total	60	55.5
Area covered by the pallets, feet	1,296	1,440
Percent of total	40	44.5
Pallets accommodated	108	120
Aisle width, feet	9	10
Number of aisles	6	5
Aisle length, feet	36	36
Length of the order picker's walk, feet	292	252

FIG. 96. *More pallet area and wider aisles* through better layout of same floor area. (*U.S. Dept. of Commerce, Industrial Series No.* 18.)

Surveys show that approximately 27 percent of plant accidents involve the material-handling operations within the plant. These surveys also reveal that the 4 principal types of accidents consist of the following:

a. Congested working space.
b. Inadequate aisle space.
c. Unsafe piling or storing of material.
d. Unsafe planning of traffic flows.



Here are two layouts of the same space. In one of them the wholesaler has laid out his assembly line in the customary way with the goods' faces parallel to the aisles, and in the other at a 45-degree angle.

With the first design he finds that he can get 130 pallets on the line and that the aisles and the stacks each occupy half the area.

With the second design he can get only 105 pallets on the line, and aisles occupy 60 percent of the space. With this design the machines can approach the goods easily, as shown by the arrow, without the need for making a short turn at a right angle. But there has been considerable waste of space. Such waste is unavoidable, for the distance across the aisle between stack corners has been reduced to the diagonal width of one pallet, as shown by the connecting bar in the drawing, and therefore can be reduced no more.

The inevitable conclusion must be that diagonal stacking, displaying more than one stack side to the order picker, can never equal the space-use efficiency of a right-angle arrangement on the assembly line in which the goods' faces are parallel with the aisle.

But the use of a diagonal arrangement in the storage areas does not have these shortcomings in so high a degree, for in such areas the storage may be fairly solid, with little if any aisle-space wastage. Not all the stacks in the reserve areas need be immediately accessible.

The principle is for highest proportion of space use by stacks and least by aisles while providing adequate aisle space, and exposing the least possible portion of the stack surfaces

FIG. 97. *Waste of floor space* in diagonal stacking versus right-angle stacking of pallets. (*U.S. Dept. of Commerce, Industrial Series No.* 18.)

These four major causes of accidents may be directly influenced by the work of the plant layout engineer.

It is not deemed feasible for the designers and manufacturers of material-handling equipment to anticipate all possible hazards that may arise at various plants as the result of using their mechanical devices. Proper planning in the application of this equipment by plant layout engineers can aid materially in avoiding many of the hazards attributable to careless operations. Much effort is being devoted by the following organizations to promote safety practices and standardize the designs and applications of material-handling devices:

a. American Standards Association.
b. National Safety Council.
c. American Society of Mechanical Engineers.

d. **American Institute of Electrical Engineers.**
e. **American Material Handling Society.**
f. **Society of Industrial Packaging and Materials-Handling Engineers.**
g. **American Society of Safety Engineers.**

4. FITTING THE EQUIPMENT OPERATIONS TO THE VOLUME OF ACTIVITY

Scope of Physical Characteristics

Securing a detailed description of the material to be handled, its condition, shape, size, and weight, and the type and size of container (if any) it will be handled in marks a major step in developing a material-handling project. Another major step is taken when building plans, plot plans, layout plans, and data on the characteristics of the building are obtained. These two steps cover the extent of the data needed on physical characteristics.

Variable Factors

The remaining phase of the approach to the material-handling project has to do with the variable factors surrounding the handling activity and cost analysis of the project. This phase of the development is divided into two sections, namely:

a. Fitting the equipment operations to the volume of activity.
b. Labor cost, equipment operating cost, and net benefits.

Handling Activity

Our concern in the present section is with the first of these two topics, namely, the *handling activity*. Let us now return to the check list on page 196. According to the check list, the handling activity of a project consists of the following four main divisions: (*A*) handling operations; (*B*) equipment used; (*C*) distance moved; and (*D*) volume of operations. These four headings are further subdivided into a total of nine subheadings.

An **actual illustration** of the application of these divisions and subdivisions of handling activity will assist in understanding their interrelationship as factors leading up to the **number of material-handling operations per year.** For this purpose, let us continue to use the steel tanks described previously under the topic, "Material and Container," and refer to Table 6 on page 206.

(*a*) *Starting point.* Each item is considered at each move, from its entrance into the plant to the time it becomes a part of the finished assembly. Movements are listed in sequence of performance. The plant layout engineer must know how many times material is lifted, moved, and set down during each handling step. Re-layouts of existing facilities usually change the number of movements an item must make. And a new plan frequently changes the condition and position of the material before each move. The engineer takes these factors into consideration in listing the handling operations required to move the item through the manufacturing cycle. The four operations listed here account for only a representative part of the entire manufacturing cycle for these steel tanks.

TABLE 6. HANDLING ACTIVITY

No.	*A*. HANDLING OPERATIONS			*B*. EQUIPMENT
	Starting Point (*a*)	Handling Operation (*b*)	Stopping Point (*c*)	Material-Handling Equipment (*d*)
1	Floor	Load truck	Truck	Truck (12 pieces)
2	Bay F-20	Transport truck	Bay A-90	1 truck
3	Truck	Unload truck	Pallet	Pallet (7 pieces)
4	Floor	Stack pallets	6–7 High	Fork lift truck

No.	*C*. DISTANCE	*D*. VOLUME OF OPERATIONS			
	Distance Moved (*e*)	Quantity of Pieces		Operations per Year (*h*)	Operation Unit (*k*)
		Per Year (*f*)	Per Operation ÷ (*g*) =		
1	30′	125,591	÷ 1 =	125,591	Pieces
2	1,630′	125,591	÷ 24 =	5,233	Trips
3	5′	125,591	÷ 1 =	125,591	Pieces
4	50′	125,591	÷ 7 =	17,942	Loads

(*b*) *Handling operation.* Only when speed and efficiency are combined in the handling of materials can productive equipment be kept constantly in operation at maximum capacity. Much effort is wasted in handling, piling, unpiling, and storing of materials because of poor layout of manufacturing and storage areas and because of improper types of handling devices used. It must be decided at the outset whether materials are to be moved horizontally or vertically, and how much piling, loading, and unloading will be required. Provision must also be made for the accumulation of empty containers while awaiting to be returned for reuse.

(*c*) *Stopping point.* These are the locations to which materials are moved. A great many plants still depend on skilled help to bring material to, and take it away from, their work stations. After cutting corners to save a few cents on the cost of a part, many companies still spend a lot more cents to move the part around the plant.

But with a modern handling system in the plant, these workers are able to stay at their machines or work stations and keep producing while material is brought to them and removed in quantity. Planned material handling makes it possible to avoid much of the "muscle moving" still going on in many plants.

(*d*) *Material-handling equipment.* The movement requirements must be analyzed thoroughly to determine the best type of handling device to take care of production needs. An analysis of the project must be made to determine the truck, trackless train, conveyor, crane, or hoist equipment best suited for the job. The plant layout engineer has to know the types and number of material-handling equipments now in use. He must also know the load capacity of each type of device, and where it is used. For the system selected to handle 60 boxcars of metal chips a month in an aircraft factory during World War II, see Figure 98.

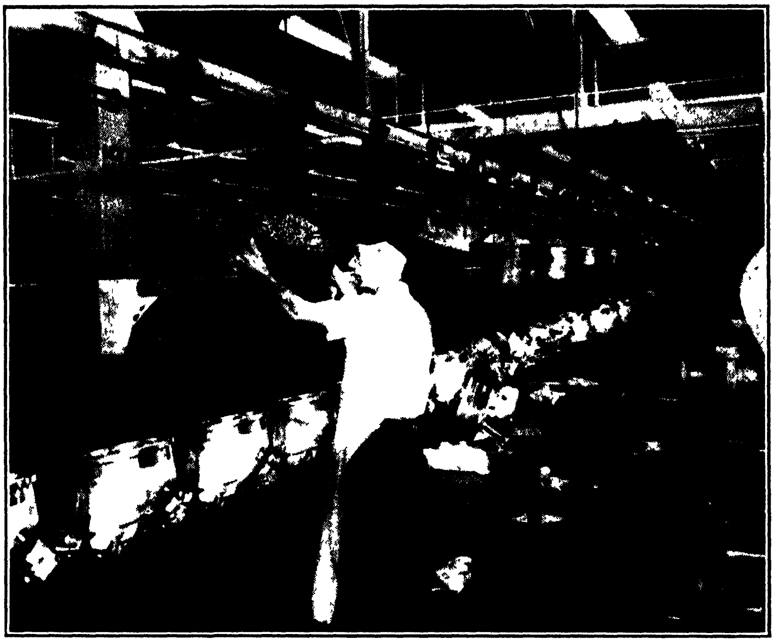


FIG. 98. *Handling 60 boxcars of metal chips a month* during the wartime production of aircraft-engine cylinder heads at the Kansas City government plant operated by the Pratt & Whitney Aircraft Corporation. *Chips followed the castings.* The chips were gathered at each machine and scraped into a small bucket. The buckets were hung on an overhead trolley conveyor that passed near almost every machine in the department. The conveyor delivered the buckets to the chip room for screening, drying, storage, and shipment. The same conveyor also brought the empty buckets back and served as a storage line for both full and empty buckets. The line was directly above and followed the path of the roller conveyor on which the castings were moved from one operation to the next. (*Courtesy of Albert Kahn Associated Architects and Engineers, Detroit.*)

These facts provide him with a picture of the tools he has to work with and enable him to suggest what equipment changes, if any, are necessary to streamline the flow of production. Equipment needed in one department should be adaptable to possible future uses in other departments. Standard tracks, roadways, container sizes, etc., permit the shifting of equipment to avoid the development of bottlenecks at unforeseen times.

(*e*) *Distance moved.* This tells how far the material has to be moved each time. An analysis of the distances traveled on the production floor in moving materials from operation to operation often leads to the relocation of machinery and equipment, as well as to a revision in the sequence of manufacturing operations. Where provision can be made in the layout to store as much material as possible near or within the work-station area, much will be accomplished toward solving the material-handling problem. In studying the routes followed by the material, the plant layout engineer can often eliminate needless backtracking and detours.

(*f*) *Quantity of pieces per year* divided by (*g*) *Quantity per operation* results in (*h*) *Operations per year.* It will be noted in Table 6, column (*d*), that, as the product moves along its path of travel, the types of handling devices change from hand trucks to pallets and then to fork-lift trucks. Furthermore, the operation unit in column (*k*) likewise changes from pieces to trips, back to pieces, and finally to loads.

The operations at each move in column (*h*) consequently change in number from 125,591 to 5,233, back to 125,591, and finally to 17,942. Unless these figures are recorded in clear-cut columnar form as shown in columns (*g*) and (*h*), distorting errors will creep into the engineer's calculations. Although there is but one volume of activity, namely, 125,591 tank units involved in the illustration in column (*f*) the number of operations per year in column (*h*) varies from 125,591 down to 5,233, depending upon the particular type of material-handling equipment used.

5. LABOR COST, EQUIPMENT OPERATING COST, AND NET BENEFITS

Cost Analysis

The final phase in planning the material-handling project consists of converting the handling activity into **labor cost** and **operating cost,** as illustrated in Table 7. This table is but a continuation and completion of Table 6 used above to illustrate **handling activity.**

(*m*) *Labor hours per operation.* The time values considered here are for material handlers whose specific work consists of loading, transporting, and unloading the material at each handling. The values do not include the time spent by machine operators or assembly workers in handling material to and from operations nor in waiting for material. These time values are for handling operations by material handlers only, and should not be estimated by the plant layout engineer who is analyzing the handling problem. Since these figures will ultimately affect the pay rates of the material handlers, the plant time-study engineers should analyze the proposed handling methods and assign the time values.

(*h*) *Number of operations per year* multiplied by (*m*) *Labor hours per operation* give (*n*) *Labor hours per year.* A further multiplication of (*n*) *Labor hours per year* by (*p*) *Wage rate per hour* provides (*r*) *Labor cost per year.* The wage rate per hour (*p*) is calculated as the average base rate of all labor engaged in the performance of material-handling operations.

TABLE 7. COST ANALYSIS

Operation	*D*. OPERATIONS	*E*. LABOR COST			
	Number of Operations per Year (*h*)	Labor Hours per Operation × (*m*) =	Labor Hours per Year (*n*)	Wage Rate per Hour × (*p*) =	Labor Cost per Year (*r*)
1	125,591	× 0.018 =	2,261	× $0.90 =	$2,035
2	5,233	× 0.460 =	2,407	× 0.90 =	2,167
3	125,591	× 0.018 =	2,261	× 0.90 =	2,035
4	17,942	× 0.063 =	1,130	× 0.90 =	1,017

Operation	*E*. LABOR	*F*. EQUIPMENT OPERATING COST			*G*. TOTAL
	Labor Hours per Year (*n*)	Operating Hours per Year (*s*)	Operating Cost per Hour × (*t*) =	Operating Cost per Year (*u*)	Total Handling Cost per Year (*v*)
1	2,261	None	None	None	$2,035
2	2,407	2,407	× $0.37 =	$891	3,058
3	2,261	None	None	None	2,035
4	1,130	1,130	× $0.57 =	644	1,661

(*s*) *Operating hours per year.* When a material-handling operation requires the services of only one worker, the operating hours per year for the handling device (if one is used) are the same as (*n*) *Labor hours* per year. Where more than one worker is required for the handling operation, however, the number of man-hours (*n*) must be divided by the number of workers per operation to arrive at (*s*) *Equipment operating hours per year.* It is unwise to use mechanical handling equipment when a handling operation occurs infrequently over the period of a month to the point where the labor effort saved by the device does not justify the capital investment in it, unless inevitable because of safety requirements.

(*t*) *Operating cost per hour.* All too frequently, the costs of depreciation, maintenance, fuel, and supplies for operating the equipment are overlooked when considering the desirability of one type of equipment over another. Some types of equipment have a high breakdown frequency on certain types of jobs. There is no point in using a particular type of device to eliminate one man if it will require an additional man to maintain it. The "out-of-production" time must also be given careful consideration.

(*s*) *Operating hours per year* multiplied by (*t*) *Operating cost per hour* yields the product (*u*) *Operating cost per year* which, when added to (*r*) *Labor cost per year,* results in (*v*) *Total handling cost per year.*

Since the life of a layout in intermittent manufacturing operations may range from 6 months to 36 months, it is necessary to consider whether the equipment being proposed will be readily adaptable to changes in plant layout. Another point to consider is that the man-hours and machine-hours lost in productivity during a change-over of material-handling methods is lost time which cannot be recovered.

PART 3 · DESIGNING PLANT SERVICE FACILITIES

CHAPTER XIII

Receiving, Shipping, and Warehouse Areas

1. DETERMINANTS OF RECEIVING AND SHIPPING AREAS

More Weight Received than Shipped Out

Recent surveys made of the total weight of material received in a plant as compared to the total weight shipped out indicate that, by and large, 20 percent more weight is received than is shipped out. The excess in receipts over shipments is attributable to shrinkage in processing, scrap, waste, and consumption of materials and supplies in maintenance activities. Before materials can be processed in a plant they must be received, tallied, inspected, stored, and rehandled out of storage for release to the manufacturing cycle. After the material has been processed, assembled, and packed, it must again be received, tallied, inspected, stored, and rehandled out of storage for release to outbound shipping.

The intermediate storage in either stage of production may range from temporary floor storage up to prolonged warehousing of raw, worked, or finished materials. The size and design of areas required for receiving and shipping activities vary considerably with each industry, plant site, plant layout, type of product, receiving lots, shipping lots, characteristics of the material and product, practices of suppliers, carriers, and customers, seasonal limitations, market fluctuations, weather conditions, and a host of other factors which differ in each industry.

Flow of Material Is Core of Plant Layout

In many plant layouts, primary consideration is given to the accommodation of manufacturing processes, and but secondary attention is paid to the requirements of receiving, shipping, and warehousing operations. Needless to state, such layouts are usually found to be unworkable in actual operation because of delays, confusion, "bottlenecks," and excessive rehandling occurring at the receiving and shipping ends of the plant. The flow of material through the plant is, of course, the core of the entire plant layout. But this core must have both an intake and an outlet at strategic points in order for a smooth internal flow to exist. Since all the material that flows through process and assembly must pass through the receiving and shipping ends of a plant, these two areas require the same close attention in a plant layout as is given the process flow itself.

An illustration of this requirement is provided in the two photographs of an Akron plant of the Goodyear Tire and Rubber Company appearing in Figures 99 and 100. Material is received by railroad at one end of the plant, and the finished product is shipped out by truck at the other end. Between these two vital portals stands the main body of the plant, wherein the processing is carried on. Without adequately planned receiving and shipping facilities, at extreme ends of this plant, the flow of work through the plant would come to a standstill.

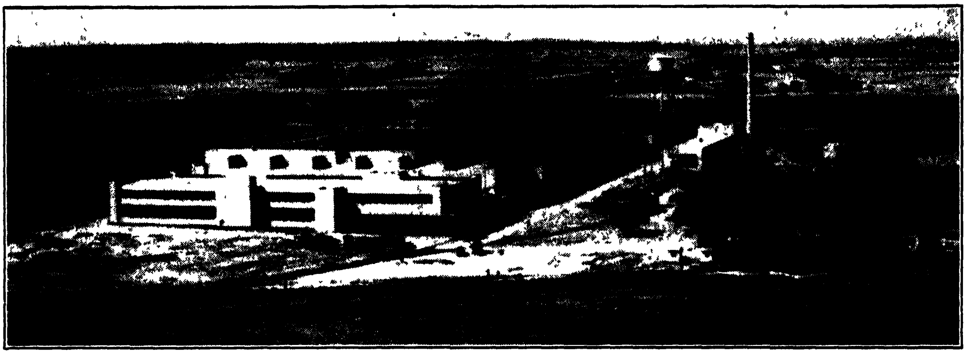


FIG. 99. *Receiving end of plant* of Goodyear Tire and Rubber Company, Akron, Ohio, showing railroad in foreground, and bifurcating sidings to right of the plant. Note truck pavement leading up to area of powerhouse.

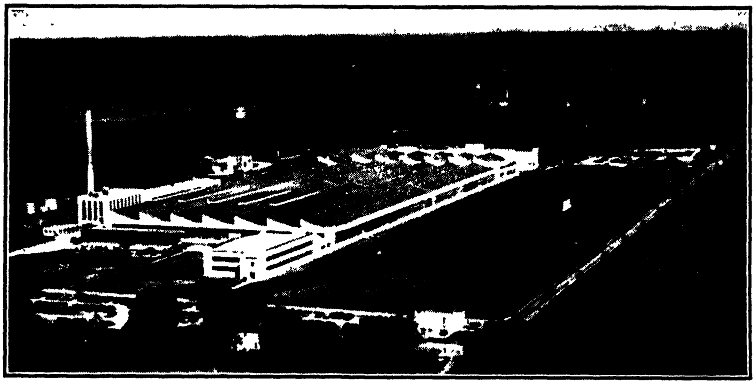


FIG. 100. *Shipping end of same plant.* Highway is in right foreground, and truck port is at left end of building near powerhouse area. Note absence of railroad siding at this end, and continuation of truck pavement separating the powerhouse from the plant.

Straight-Line Flow

The ideal flow of material through a plant would be a direct line from receiving, passing through processing, and terminating with shipping without backtracking, crossovers, or rehandling in storage. Starting with this ideal as a general determinant, the plant may then be laid out with this pattern in mind. The receiving area may be at the opposite end of the plant from the shipping area,

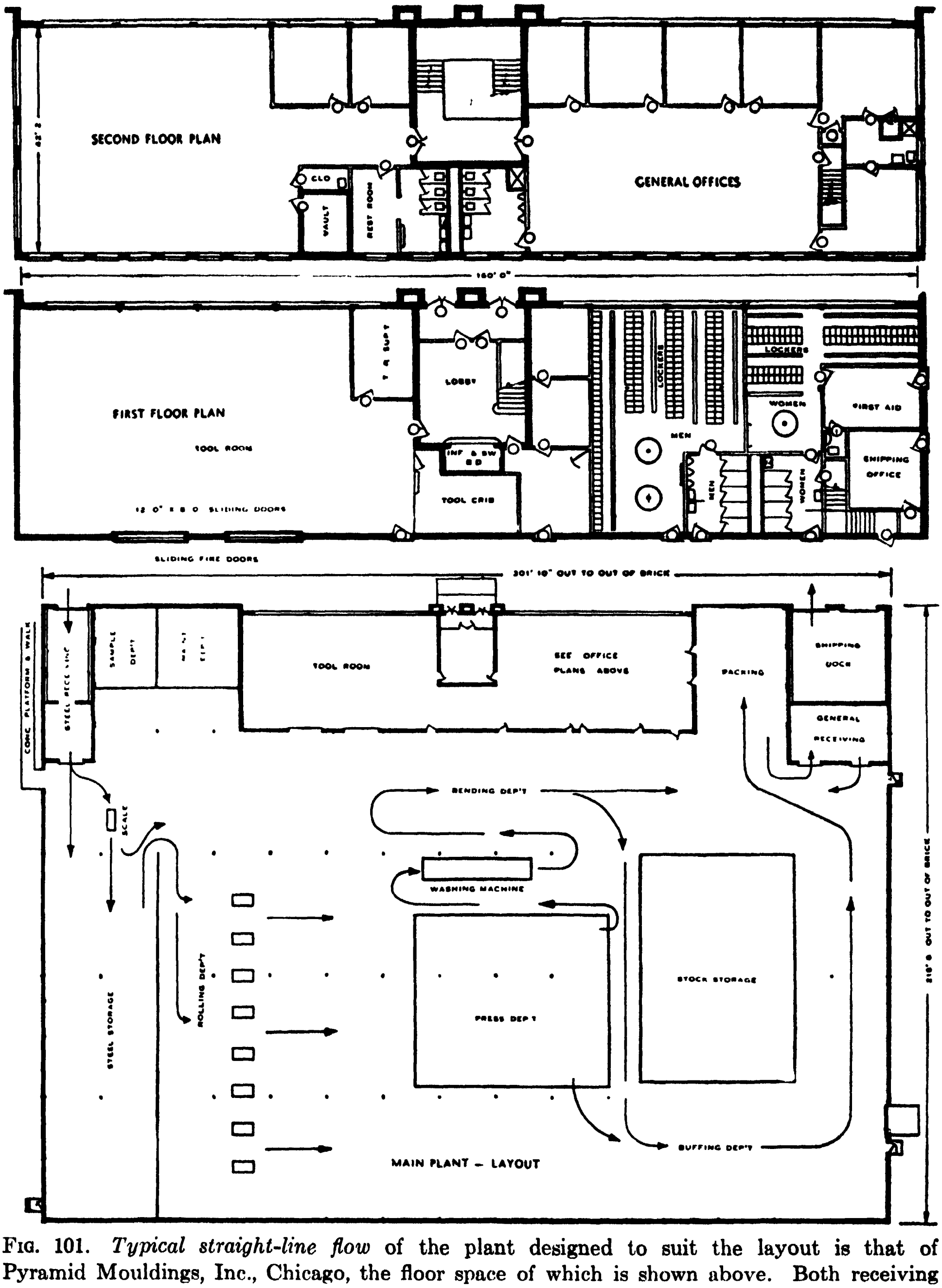


FIG. 101. *Typical straight-line flow* of the plant designed to suit the layout is that of Pyramid Mouldings, Inc., Chicago, the floor space of which is shown above. Both receiving and shipping front on the street and each is served by an enclosed, ramped loading dock. Steel enters at Receiving, passes in a straight line to the scales and steel storage, and from there progresses through to Shipping. There is some zigzagging as certain operations are by-passed or diverted. Otherwise the flow of materials is straight-line for all practical purposes. (*Courtesy of* The Tool Engineer.)

or the areas may be adjacent to each other at one end of the plant, as is shown in Figure 101. The location of each area is, in this case, as much determined by the situation of the plant site with relation to the street as by the flow of material within the plant. Steel enters at one corner of the plant and passes in a straight line to the scales and storage. It then continues in a straight flow through processing and emerges at the other corner of the building, on the same street, in the shipping dock. This straight flow has been made possible by designing the plant to suit the layout as against designing the layout to fit the plant.

2. FACTORS TO BE CONSIDERED IN A RECEIVING DEPARTMENT

Types of Carriers Servicing a Plant

Material received at a plant arrives via the particular forms of transportation which are generally prescribed by the customs and practices of the suppliers. Liquids, such as chemicals and oils, are received in tank cars, tank trucks, or in drums or smaller containers carried in boxcars and highway dry trucks. Some liquids are received in tank steamers, barges, or by pipeline. Solid material in bulk, such as steel sheets and plates, bar stock, farm produce, raw pulp, slate granules, machinery, lumber, and textiles, may be received in different types of rail cars, trucks and trailers, water-borne carriers, and by air transportation. Packaged material is frequently received by express and through the mails. By whatever mode of transportation the material may be received, the receiving department must be designed to accommodate the types of carriers that reach the plant, particularly those carriers that transport the greater portion of the material received.

The receiving department is often thought of as merely a place where a freight car or a road truck can discharge a load. Accommodations designed for one freight car today may later be called upon to serve a number of freight cars to avoid incurring demurrage. In northern latitudes where winter weather is severe, truck ports are frequently constructed deep enough to house the trucks, or tractors and trailers, thereby providing shelter while loading or unloading. Freight cars are also inclosed in sheds for inside loading and unloading. When the car dock is thus inclosed, it is permissible to narrow the gap between the car side and the dock, thus providing easier access for industrial trucks in handling material in and out of rail cars.

Designing a Receiving Department

Based on variables of this type, a number of general factors are cited below for consideration in designing the layout of a receiving department or area for a plant.

FUNDAMENTAL CONSIDERATIONS IN DESIGNING A RECEIVING DEPARTMENT

1. **Space.** Adequate space is needed in the plant yard, or inclosed receiving area, to permit ease of shifting and of spotting rail cars to avoid demurrage, as well as to

permit maneuvering trucks, tractors, and trailers wherever the material is received in these vehicles. The unloading dock or area has to be large enough to accommodate the heaviest traffic conditions likely to occur on frequent occasions.

2. **Climate.** Where climatic conditions might damage the materials, impair the movement of the vehicles, or interfere with the efficiency of the workers unloading the vehicles, it is desirable to provide a shelter over the unloading area.
3. **Carriers' codes.** Safety is a paramount requisite in carriers' codes concerning delivery of material at a plant. When safety regulations laid down by a carrier are not complied with, the carrier may refuse to serve the plant. Familiarity with the safety codes of the various transportation facilities available to a plant is essential in designing the layout of a receiving department.
4. **Mechanization.** Wherever economically justifiable, mechanical handling equipment for loading and unloading incoming vehicles should be incorporated in the layout.
5. **"Setdown" areas.** The areas provided for setting down and classifying the materials being unloaded from incoming vehicles should be designed to permit clear visibility of the materials and ease of their identification.
6. **Inspection.** When inspection of the material is necessary upon receipt, it is desirable to conduct the inspection while the material is in transit in its path of travel to the plant, so as to avoid rehandling. In laying out inspection stations for this purpose, refer to Chapter XV, "Test Areas, Inspection Points, and Dispatch Stations."
7. **First operation.** Much intermediate handling and storage can be eliminated whenever the layout permits receiving the materials at their point of first use. Receiving materials in this manner might justify the existence of several receiving points in a plant.
8. **Variety of vehicles.** If materials are received in more than one type of transportation vehicle, such as in both rail cars and road trucks, the receiving dock is laid out so as to avoid conflicts between the different types and yet provide flexibility of adaptation. Otherwise, it frequently turns out that trucks have to back over trackage or that spotted cars prevent the trucks from getting access to the receiving dock. Many of these conflicts can be eliminated through proper layout planning.
9. **Dock height.** Where rail cars and road trucks are received at a common dock, it is preferable that the height of the dock be made to coincide with the bed height of the car. In order to accommodate the trucks, wedge boards are placed on the ground in such a way as to cause the rear end of the trucks to rise as the trucks back up against the dock. Where justified, hydraulically adjustable dock sections are frequently installed.

3. DESIGN OF TRUCK- AND RAIL-LOADING FACILITIES

By far the most common types of carriers servicing industrial plants and commercial enterprises are the road truck and the railroad freight car. Very few plants do not use either or both of these transportation facilities. It becomes desirable, therefore, to examine these facilities in specific terms before proceeding with other aspects of receiving and shipping areas.

Platforms for Highway Motor Trucks

In laying out a loading or unloading platform for highway motor trucks, the first point to consider is the **maximum number** of these vehicles which must be accommodated at the present time, and the number that the plant may have to accommodate 10 or 15 years hence. For flexibility of expansion, see the shipping dock in Figure 102.

A decision must next be made regarding the necessity of providing **shelter** for the truck units, tractor and trailer combinations, etc., while loading or unloading. The next capacity factor to be determined is the provision for the **over-all dimensions** of the various types of motor trucks.

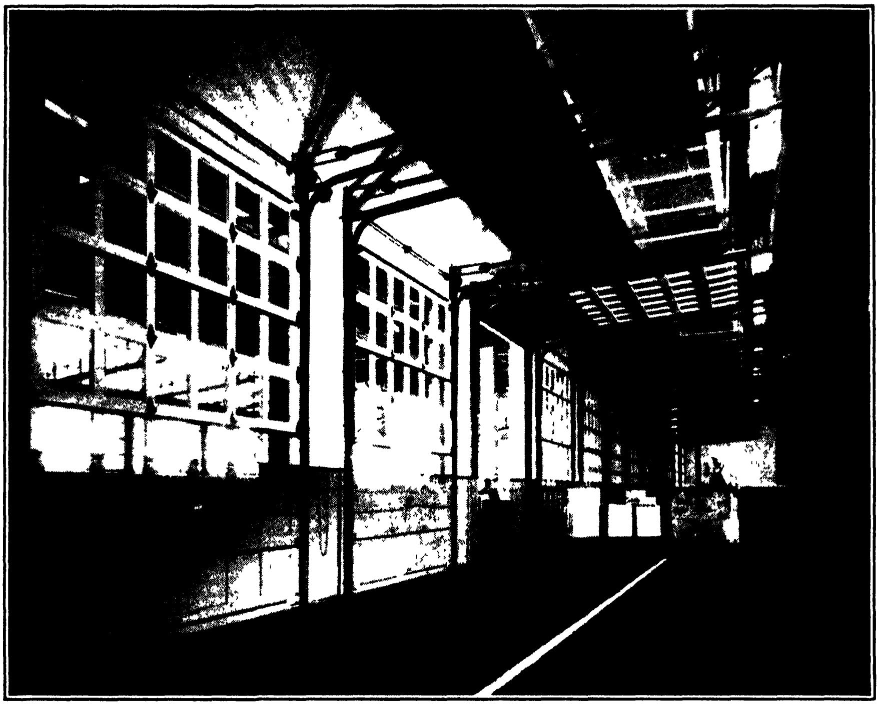


FIG. 102. *Shipping dock with overhead doors.* The effective use of overhead doors in place of fixed partitions, to expedite the movement of incoming and outgoing materials, is illustrated in the shipping dock of the Kansas City plant of the Pratt & Whitney Aircraft Corporation. These doors also provide an effective air lock. Note the wide, clear aisles to permit unobstructed truck movements. (*Courtesy of Albert Kahn Associated Architects and Engineers, Detroit.*)

These dimensions are given in graphic form in Figure 103, and are summarized in Table 8.

Various Heights in Truck-Bed Levels

Because of the lack of uniformity in the level of truck beds, the use of material-handling equipment in loading or unloading trucks from the building platform gives rise to the problem of determining the proper height of the platform level which will best meet the various truck-bed levels. Truck decks vary as much as 1 foot in height.

This problem is sometimes solved by making a portable ramp by sawing 12-inch timber diagonally through the cross-section, along the entire length of the

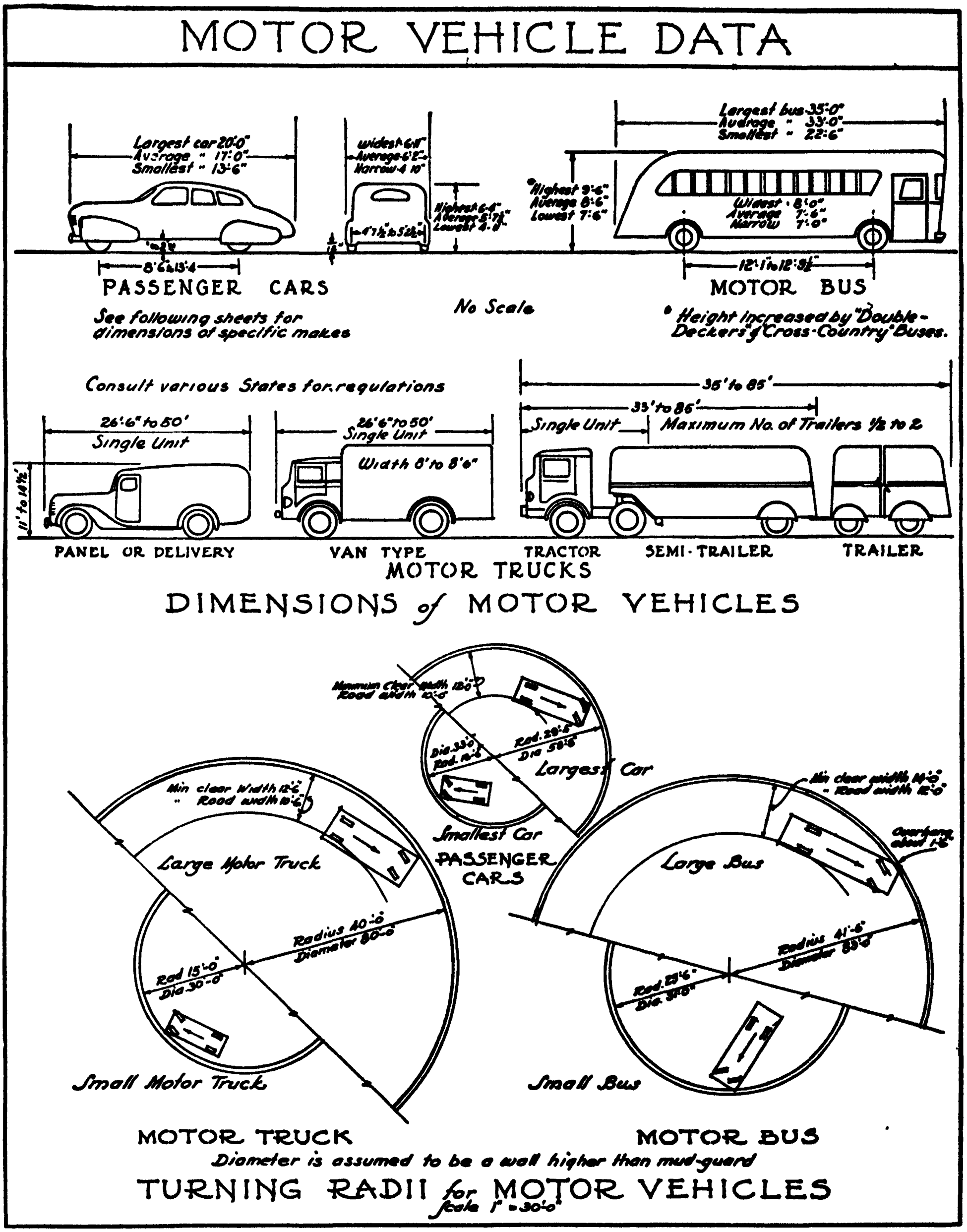


FIG. 103. *Motor vehicle data.* (*From* Architectural Graphic Standards, *by Ramsey and Sleeper, John Wiley & Sons,* 1941.)

TABLE 8. OVER-ALL DIMENSIONS OF MOTOR TRUCKS

	Range
Length: single-unit motor truck	26′ 6″ to 50′
tractor and semi-trailer or trailers	33′ to 85′
Width: all types of motor trucks	8′ to 8′ 6″
Height: all types of motor trucks	11′ to 14′ 6″
Turning radius: all types of single units	15′ to 40′

timber, thus converting the rectangular piece into two triangular pieces. To lift the truck deck to the level of the dock platform, the rear wheels of the truck are backed onto the ramp, thus lifting the truck tailgates to the platform level. The adjustable-height dock section is a more effective solution to this problem where traffic is heavy. It can be continuously adjusted as the vehicle is loaded or unloaded and the bed height keeps changing. Inadequate docks are characteristic of old plants and are a source of congestion, delay, and high costs.

Leveling Car Floors to Dock Platforms

The problem of bringing railroad-car floor levels into agreement with the level of the dock platform does not lend itself for solution by the ramp idea. Gangplanks are used effectively to connect the car floor with the platform when the difference between the two levels is not great enough to cause the unloading equipment to spill the load in traveling over the gangplanks. When one level is considerably higher than the other, the problem requires special analysis to determine the most suitable type of material-handling equipment to use in loading or unloading the cars.

Dimensions of Railroad Cars

Clearance diagrams and dimensions for railroad cars are shown in detail in Figure 104. The measurements of railroad cars are summarized in Table 9.

Railroads often use special cars ranging up to 80 feet in length. Shippers utilizing pallets for shipping material in "unit loads" (see Figure 105) often use automobile freight cars which are 60 feet in length. The door arrangement in these cars permits better access for loading with fork trucks. When the activities of a plant necessitate the contemplated use of cars 60 or 80 feet in length, provision for these lengths must be made in the plant layout.

Combining Truck-Loading and Rail-Loading Facilities

A platform designed for loading or unloading either motor trucks or freight cars is illustrated in Figure 106. Two road trucks and five freight cars can be loaded at one time on this platform, which is fully inclosed in a trussed-roof building. The overhead crane facilitates the loading of open trucks and rail cars. Hand jacks, power-lift trucks, or fork trucks can be used for loading closed trucks or box cars. All handling operations are sheltered, thus enabling the operators to work with the same degree of efficiency throughout the year.

A trench-type floor drain has been provided to keep the floor clear of water in bad weather. The overhead crane is equipped with a push-button pendant con-

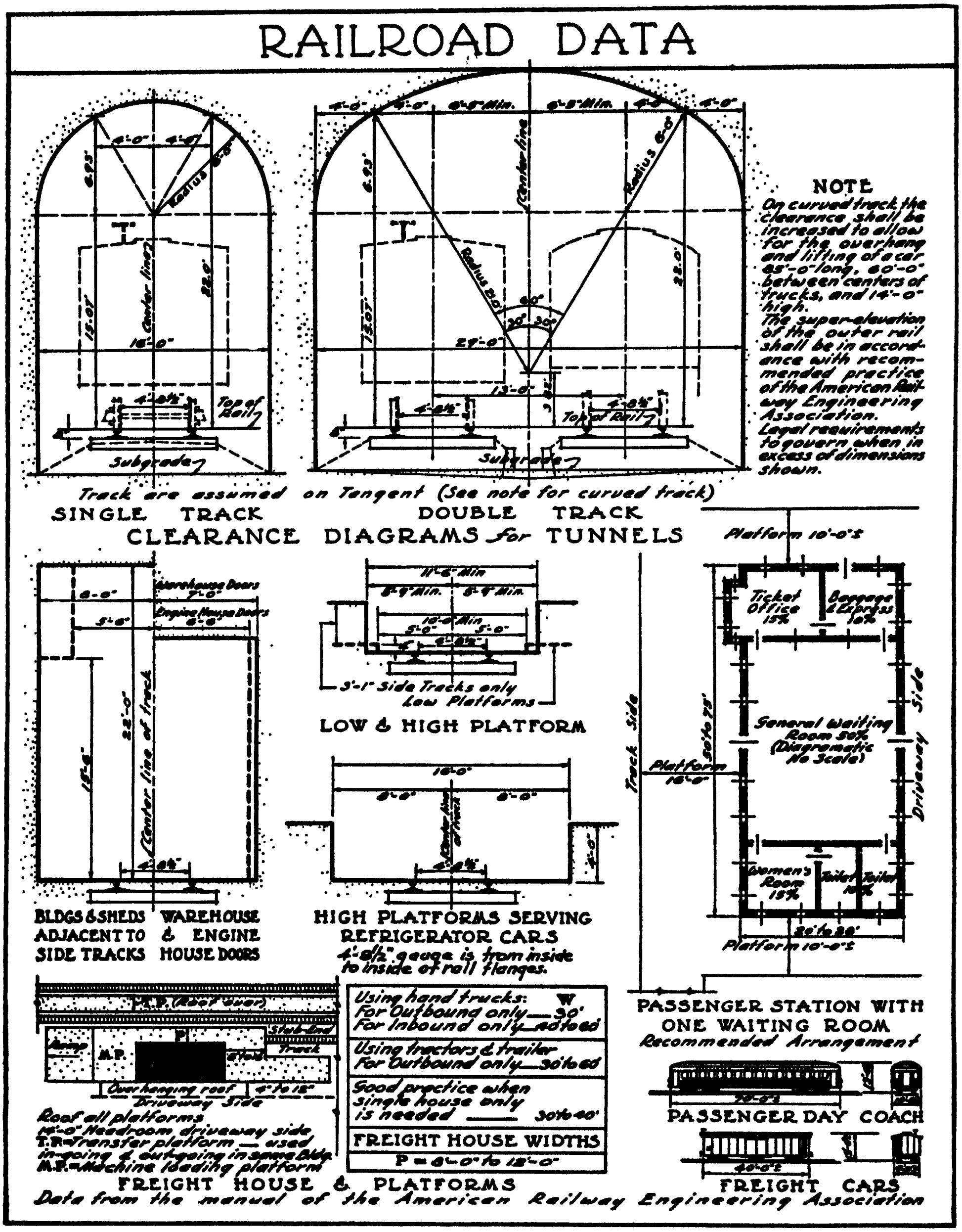

RAILROAD DATA
NOTE
On curved track the clearance shall be increased to allow for the overhang and lifting of a car 85'-0" long, 60'-0" between centers of trucks, and 14'-0" high.
The super-elevation of the outer rail shall be in accordance with recommended practice of the American Railway Engineering Association.
Legal requirements to govern when in excess of dimensions shown.
Radius 6'-0"
Radius 20'-0"
Center line
Top of Rail
Subgrade
4'-8½"
16'-0"
29'-0"
13'-0"
22'-0"
15'-0"
6'-9"
Track are assumed on Tangent (See note for curved track)
SINGLE TRACK
DOUBLE TRACK
CLEARANCE DIAGRAMS for TUNNELS
Warehouse Doors 7'-0"
Engine House Doors 6'-6"
Center line of track
BLDGS & SHEDS ADJACENT TO SIDE TRACKS
WAREHOUSE & ENGINE HOUSE DOORS
11'-6" Min
5'-9" Min.
10'-0" Min
5'-0"
3'-1" Side Tracks only Low Platforms
LOW & HIGH PLATFORM
16'-0"
8'-0"
4'-0"
HIGH PLATFORMS SERVING REFRIGERATOR CARS
4'-8½" gauge is from inside to inside of rail flanges.
Platform 10'-0"±
Ticket Office 15%
Baggage & Express 10%
General Waiting Room 50% (Diagramatic No Scale)
Women's Room 15%
Toilet
Toilet 10%
Track Side
Driveway Side
Platform 16'-0"
50' to 75'
25' to 35'
PASSENGER STATION WITH ONE WAITING ROOM
Recommended Arrangement
T.P. (Roof over)
Stub-End Track
Ramp
M.P.
P
Overhanging roof
4' to 12'
Driveway Side
Roof all platforms
14'-0" Headroom driveway side
T.P.=Transfer platform — used in-going & out-going in same Bldg.
M.P.=Machine loading platform
Using hand trucks: W
For Outbound only — 30'
For Inbound only — 40' to 60'
Using tractors & trailer
For Outbound only — 30' to 60'
Good practice when single house only is needed — 30' to 40'
FREIGHT HOUSE WIDTHS
P = 8'-0" to 12'-0"
FREIGHT HOUSE & PLATFORMS
70'-0"±
PASSENGER DAY COACH
40'-0"±
FREIGHT CARS
Data from the manual of the American Railway Engineering Association

FIG. 104. *Railroad data.* Data from the manual of American Engineering Association. (*Reproduced from* Architectural Graphic Standards, *by Ramsey and Sleeper, John Wiley & Sons,* 1941.)

TABLE 9. OVER-ALL DIMENSIONS OF RAILROAD CARS

		Range
Length:	standard railroad car	32′ to 53′
	average boxcar	40′ to 50′
Width:	standard railroad car	7′ 3″ to 10′ 6″
	average boxcar	9′ to 9′ 2″
Height:	clearance above top of rail	13′ to 15′ 6″
	car floor above top of rail	3′ to 4′

trol which makes it possible for one worker to hook on the load and operate the crane from the floor. When rail cars are not being loaded, motor trucks can utilize the floor space containing the trackage. Concrete has been filled in between the tracks to permit trucks to operate over this area.

FIG. 105. *Unit loads in a glass factory.* Carton chutes from the floor above deliver made-up empty cartons down to the packing room shown here in the glass-container plant of the Brockway Glass Company, Inc., Crenshaw, Pa. At the foot of each chute is an inspection-and-packing work station using knee-high roller conveyors for workbenches. Filled cartons are pushed on these conveyors to a convenient point for unloading onto pallets. The unit loads thus made up on the pallets are then trucked to the warehouse located in another building.

Air-Freight Planes as Carriers

The day appears not too far distant when, in addition to motor trucks and rail cars, the cargo plane will take its place as one of the leading carriers. It is not to be inferred, however, that these planes will taxi alongside a plant's receiving or shipping platform to be loaded or unloaded. Although it does not seem probable that industrial plants will, in the near future, be equipped with private airports, the handling of air cargo is already a recognizable problem.

Packaging and terminal time are extremely important in handling air cargo. Excess weight of shipments or long waits at the terminal tend to neutralize the speed advantage of air shipments. The shipping department of the plant of the future will inevitably be equipped for the quick and efficient weighing and handling of loads to and from airports. In planning new plants this problem should be given careful study and consideration.

FIG. 106. *Combination truck-loading and rail-loading facilities.* Two road trucks and five freight cars can be loaded at one time in this building. The overhead crane is used in loading open trucks and rail cars. Hand jacks, power lift trucks, or fork trucks can be used to load closed trucks and boxcars. All loading operations are sheltered. Note that the crane is floor-operated with a pendant control, permitting the operator to hook and unhook loads without assistance. (*Courtesy of Gaudreau, Rimbach & Associates, Pittsburgh.*)

In Figure 107 is a cargo plane being loaded by a fork-lift truck. The interior view of this plane, shown in Figure 108, reveals that the plane has nearly the cubage of a standard boxcar. This particular plane can carry a cargo of 9 tons. The future holds promise of aircraft with a considerable increase in pay-load capacity.

4. PLANT EXPANSION WITHIN FIXED BOUNDARY LINES

Excessive Costs Hidden in a Sellers' Market

In the modernization, conversion, or expansion of existing plants, such as occurred during World War II and such as was experienced in a still more feverish degree during the reconversion period following the cessation of hostilities, time and expediency caused many operating problems to be overlooked. Notable

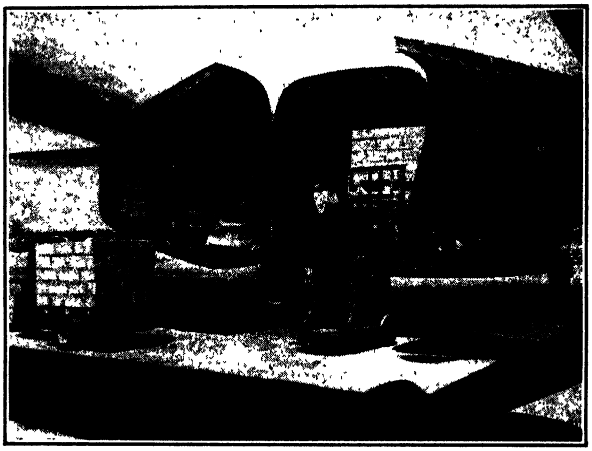


FIG. 107. *Air-freight plane,* a Fairchild "Packet," being loaded with packaged material by a fork-lift truck. (*Courtesy of Fairchild Aircraft Company.*)

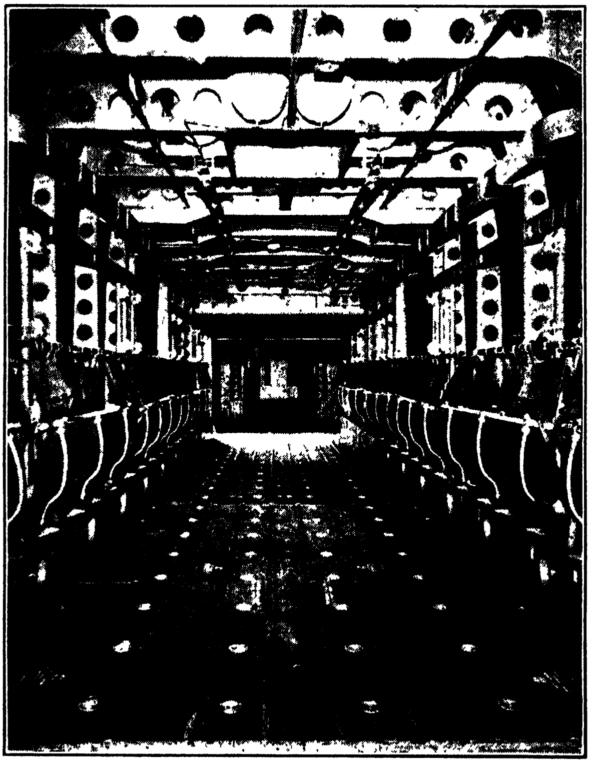


FIG. 108. *Interior view* of the Fairchild "Packet" plane. The clear area has nearly the cubical contents of a standard boxcar and can carry a load of 9 tons.

among these were the receiving and shipping problems. This apparent oversight caused many a war plant to handle materials at excessive costs. When reconverted to peacetime products, many of these plants carried these excessive costs into their postwar activities in order to rush into a waiting sellers' market characterized by an unrelenting consumer demand at inflationary prices. This demand was further accelerated by government purchases for the rehabilitation of war-devastated countries in western Europe.

The excessive operating costs arising from inadequately planned facilities for receiving and shipping materials therefore remained comparatively unobserved through being easily tolerable during the years of a war boom immediately followed by postwar years of mounting prices. The day of reckoning comes, however, when pentup market demands have subsided and the buyer begins to shop around for better prices. Competition among manufacturers to attract this buyer inevitably causes prices to come down and, in so doing, narrows the margin of profit.

Re-Layout of a "Hemmed-In" Plant

A specific example of the basic importance of properly planning receiving and shipping facilities when converting a plant for wartime production, with an eye on the postwar utilization of this plant after competition has returned, is illustrated in the foundry and factory shown in Figure 109. This is a perspective drawing of the plant as it stood just before World War II. Surrounded as it was on all sides, the only outlet remaining for expansion was in a vertical direction. Before expanding upward, however, it was necessary to provide a suitable base by demolishing a number of small buildings on the plant premises. Accompanying the razing of these buildings to the ground was the problem of abandoning a network of spur tracks without giving rise to increased costs in receiving materials and shipping products handled on these tracks.

To achieve these ends, the plant was redesigned as shown in the perspective rendering in Figure 110. Analysis revealed the existence of the following four basic receiving and shipping problems:

1. Receiving foundry and maintenance supplies by rail and truck into the foundry.
2. Shipping foundry products by truck.
3. Receiving manufacturing materials by rail and truck into the manufacturing building.
4. Shipping manufactured items by rail and truck.

One-Point and Two-Point Receiving Plans

The topography of the site necessitated that the rail entrance be confined to only one side of the plant and that the truck entrance be limited to one street. Further study pointed out that the foundry materials could be handled separately from the factory materials without loss of efficiency. In fact, handling cost could actually be reduced by bringing materials to their respective points of first use instead of relying on one common point for receiving materials. This two-point

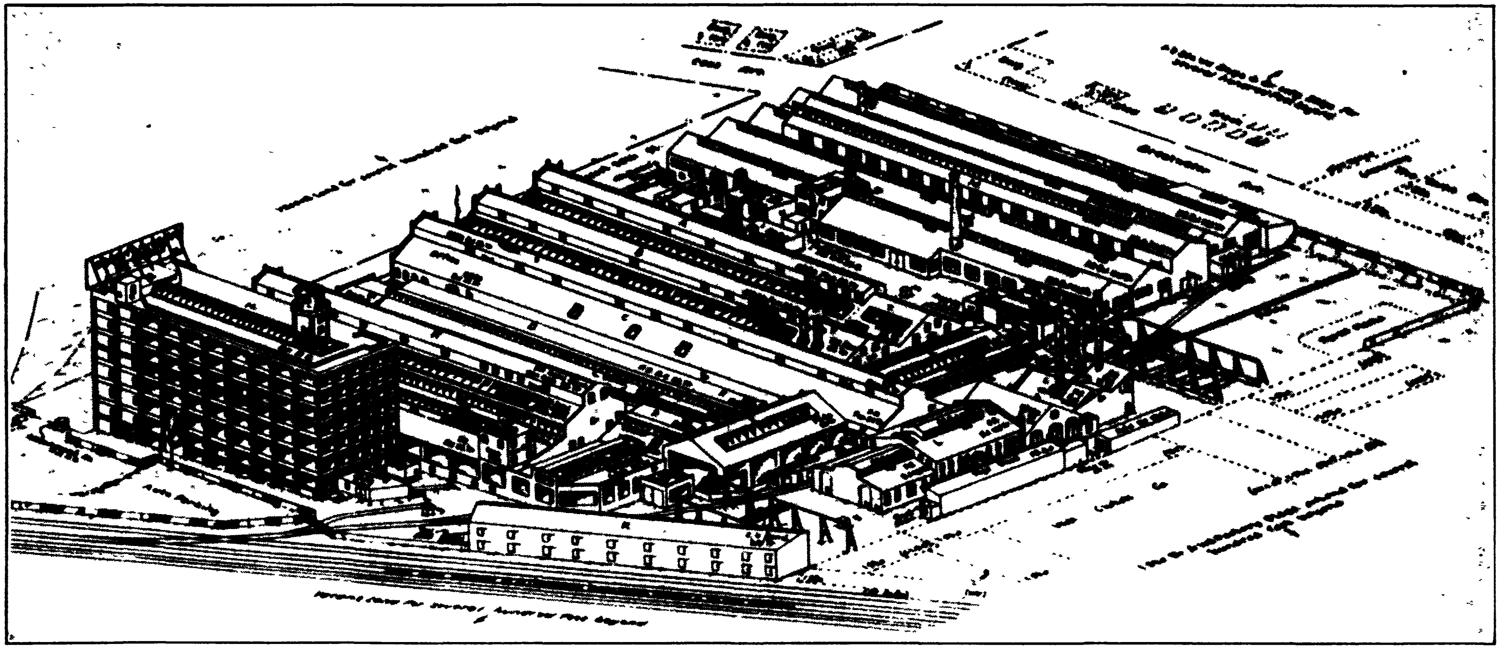


FIG. 109. *Perspective drawing before re-layout* of a foundry and factory hemmed in by streets on two sides, by a railroad on a third side, and by another plant on the remaining side, at the outbreak of World War II The only direction left for expansion was skyward. This view was taken from the rear of the property. The needed additional floor space could be provided within existing boundary lines by razing the cluster of small buildings in the foreground to make way for the projection of the multi-story main buildings towards the rear boundary line. This extension, however, would necessitate the abandonment of several railroad spur tracks used across the property for receiving raw materials and shipping finished products.

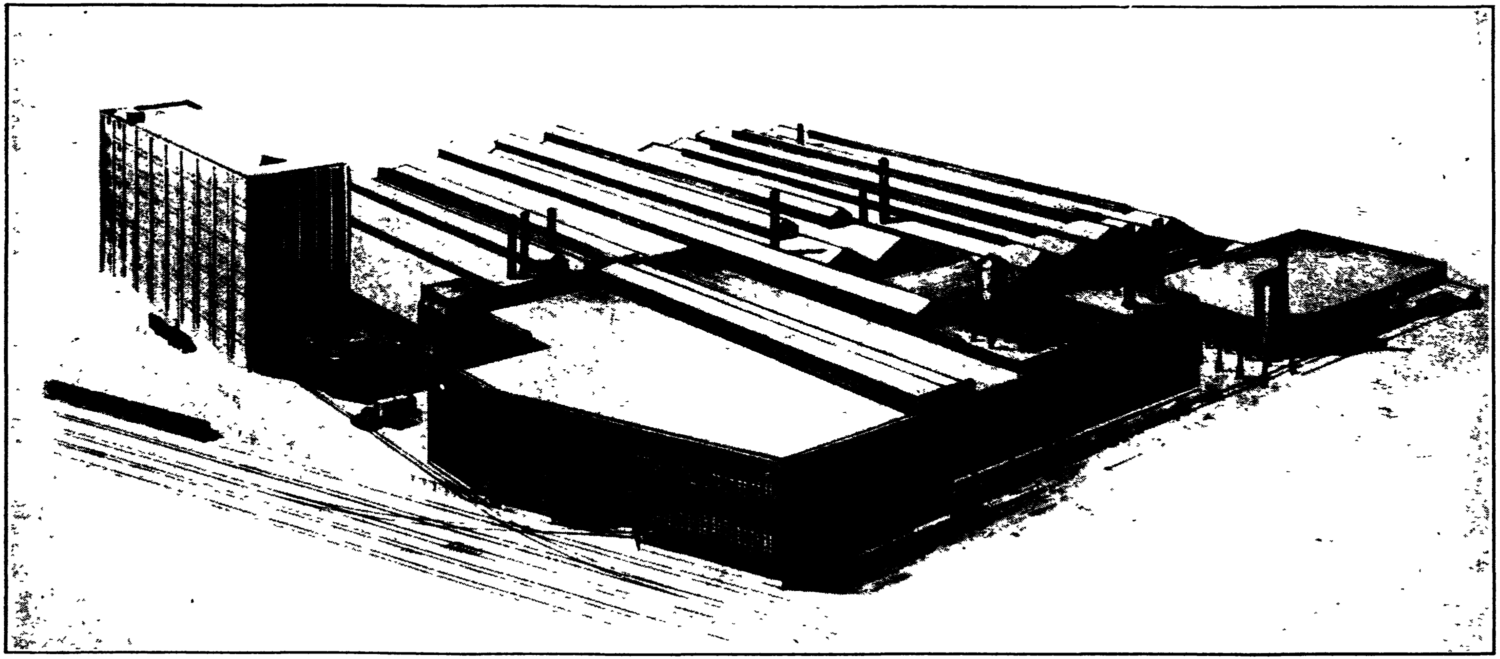


FIG. 110. *Perspective rendering of the same plant after re-layout.* The incoming rail spur passes through the new two-story building in the foreground and emerges in the rear yard to serve the coal silo, foundry supply building, and the exposed craneway used for yard storage purposes. Outgoing rail service is supplied by a new spur direct to the shipping building at the extreme left. The truck receiving dock in the new two-story building uses the same truck yard and driveway as are used for the shipping department across the way in the eight-story machining and assembly building at the far left. This arrangement conserves a considerable amount of yard space and greatly simplifies the plant protection problem.

receiving plan is actually two one-point receiving plans, namely, one for the foundry and one for the factory. The one-point receiving plan is the one usually advocated for purposes of facilitating control over materials and of guarding against duplication of effort in handling operations.

In the redesigned plant, as shown in Figure 110, the incoming rail spur passes through the two-story warehouse building and emerges into the rear yard to serve the coal silo, foundry supply building, and the craneway used for yard storage. Foundry materials are received directly at the point of use or storage, thereby minimizing handling and traffic congestion.

Significant features of this revised layout relating to the receiving and shipping facilities of the plant are highlighted below:

1. **Carloads** of material entering into the factory building are unloaded directly at the point of use, namely, in the manufacturing plant proper rather than in the foundry. The unloading is completely sheltered.
2. Material received by **road truck** can likewise be unloaded in the receiving department completely protected from the weather.
3. Raw material **inspection** takes place at the point of receiving and can thus be made without rehandling.
4. **Belt conveyors** are used for moving material from the receiving floor to the second floor. This eliminates the use of elevators and accelerates the clearing of material from receiving docks.
5. One incoming **railroad spur** serves the entire plant.
6. Trucks that unload **incoming shipments** can be reloaded with **outgoing shipments** without leaving the immediate area.
7. Receiving and shipping activities each have **separate facilities** and yet are close enough to each other to permit common use of some of the facilities.
8. **Rail shipments** are loaded from the same dock as truck shipments without causing interference. Cars are spotted outside the building, with car floor at dock level.

Excess Loading and Unloading Capacity

On a 24-hour basis, the existing loading and unloading capacity of rail cars and road trucks is greatly in excess of present requirements, and thereby permits more efficient operation by preventing the facilities from being worked to capacity limits. This excess capacity also provides a comfortable allowance for delayed railroad shifts and shipments, as well as for factory breakdowns, etc. Despite this excess capacity for loading and unloading cars and trucks, there is less trackage and driveway space in the revised layout than existed in the old layout.

5. WAREHOUSE HANDLINGS, SPACE, AND ROOF SUPPORTS

The **internal handlings of material** that occur between the receiving dock and the shipping platform in a manufacturing plant and in a commercial warehouse may be outlined as follows:

TABLE 10. INTERNAL HANDLINGS OF MATERIAL BETWEEN RECEIVING AND SHIPPING

IN A MANUFACTURING PLANT	IN A COMMERCIAL WAREHOUSE
1. Unloaded at receiving dock.	1. Unloaded at receiving dock.
2. Piled on material-handling equipment.	2. Piled on skids or pallets at dock.
3. Hauled or conveyed to storage.	3. Unit loads hauled to storage.
4. Unpiled and placed in storage.	4. Hauled from storage to assembly lines.
5. Piled on material-handling equipment.	5. Selected to fill shipping orders.
6. Hauled or conveyed to point of first use.	6. Hauled to shipping platform.
7. Stored in transit as work in process.	7. Loaded on shipping car or truck.
8. Moved from production to assembly lines.	
9. Moved to finished-product storage.	
10. Selected to fill shipping orders.	
11. Hauled to shipping platform.	
12. Loaded on shipping car or truck.	

Vertical versus Horizontal Storage Space

Seeking the reduction or elimination of some of these handlings constitutes a primary objective of laying out warehouse space. In many plants, the total space occupied for warehousing exceeds the combined area required for all production machinery, equipment, and facilities. This proportion varies of course with each industry.

The amount of space taken up for warehousing in a given plant is governed largely by the degree of the utilization made of vertical space in addition to horizontal space. It is considered better planning to lay out a warehouse according to cubage requirements than to do so solely on an area basis.

Column Obstructions

Another governing factor in laying out warehouse areas is the arrangement of column spacings. Columns are often spaced at 20-foot intervals (in multi-story warehouses). When skids and pallets are used for storing materials in the warehouse area, they should be designed to fit within the column spacings with minimum waste for clearances and in cubage used. Columns often interfere with the complete flexibility of a warehouse layout. To move material in and out from behind columns without wasting space and without incurring wasted handling is a continual problem.

Truss Roofs versus Column-Supported Roofs

Truss roofs eliminate most of these restrictions and permit greater freedom in designing the floor plan. Truss roofs have been avoided in the past in some layouts because they are more costly to build than column-supported roofs in buildings with low ceilings. However, high-tiering operations have become more common with the growing preference for one-story warehouses.

It is often possible to offset the greater construction cost of the truss roof by utilizing the "air rights" under such roofs, that is, the upper areas which were inaccessible under column-supported roofs. Now that higher ceilings are coming in under the urge to high-tier unit loads made possible by the fork-lift truck, the time may have come for a re-examination of the comparative costs of the truss roof and of the column-supported roof.

High-Tiering Operations

Large and small fork-lift trucks are capable of high-tiering pallets to the 20-foot level. Stacks of this height are made by placing a second pallet on the first one, plus two more placed in position in one lift. **Floor-load capacities** must be ascertained before planning on pallet stacks of this height.

6. MULTI-STORY VERSUS SINGLE-STORY WAREHOUSES

Two Basic Types of Warehouses

The type of structure for a warehouse has been largely determined by characteristic function of the warehouse in the receiving, handling, storing and shipping of material or merchandise. Then, too, the location of the warehouse, its size, the value of the land it occupies, internal handling costs, etc., have been contributing factors in selecting between a multi-story and single-story type of building. By and large, however, warehouses may be classified into two basic types, namely:

1. **Multi-story warehouse.** Depository for temporarily stored materials that require little processing, such as repacking, before reshipment. Usually located in large commercial or industrial centers, this type of warehouse functions as a freight terminal for railroads and ship lines, as a public warehouse for distributing merchandise out of congested cities, as a storage warehouse for furniture, or as an adjunct to a multi-story industrial plant.
2. **Single-story warehouse.** Assembling point for gathering raw materials, bulk goods, perishable products, etc., most of which undergo processing before trans-shipment. This type of warehouse is common in many manufacturing industries and in wholesale and chain-store enterprises. It functions principally as a collection depot rather than as a storage facility for prolonged periods of time.

A modern conception of a multi-story warehouse is a building of several stories and without elevators. Highway trucks negotiate every floor of the building and discharge loads directly on the particular floor where the merchandise or material is to be stored. This plan reduces internal rehandlings and completely eliminates potential bottlenecks in vertical handlings.

Present Trend in Warehouse Structures

Except for the heavily congested city locations, however, the trend is away from multi-story warehouses and towards high-ceilinged single-story buildings. One of the motivating factors behind this trend is the higher cost of vertical transportation as against that of horizontal transportation. In one industry, it was calculated that a palletized unit load could be transported 100 feet horizontally for the same cost as moving it 13 feet vertically.

Structural Costs of Warehouse Stories

The structural cost disadvantage of a multi-story warehouse is in direct ratio to the number of floors, while the cost advantage of the one-story building is in direct ratio with its squareness of shape. It may be inferred that, from the viewpoint of structural cost, the ideal warehouse building is a square, one-story structure.

A number of elements that are not a factor in the one-story building add materially to the cost of the multi-story structure. These are:

1. **Elevators,** elevator shafts, and the walls inclosing them.
2. **Heavy live-load requirements** must be provided for the several floors of the multi-story structure. In the one-story building, depending on the bearing value of the soil, there are practically no limits to what the floor will carry.
3. At least two **stairways** are required in the multi-story structure to comply with the building codes, while no stairs are needed in the one-story building.

Cost of Usable Floor Space

In the final analysis, cost comparisons between the two types of buildings have to be made on the basis of usable floor space. The costs of the gross floor area are higher for a multi-story building than for a single-story one. In the one-story building, the construction costs of the usable floor area are nearly a third less than those in a multi-story building. In addition, a considerable amount of floor space is wasted in the multi-story building for columns, elevators, stairs, approaches, and outside walls. Only the unobstructed, usable floor area creates income for amortization and dividends. Furthermore, the one-story building can be built in less working days than a multi-story building of corresponding floor space.*

* Data from U. S. Dept. of Commerce, Industrial Series 18, 1945.

CHAPTER XIV

Storerooms and Storage Facilities

1. TYPES AND FUNCTIONAL REQUIREMENTS OF STOREROOMS

Value of Material Handled in Plant

The attention given to material costs in manufacturing operations, from the time the purchase specifications are written until the time the finished product is shipped out, varies in intensity along the line. In fact, the interest in material invariably blows hot and cold at different stages of the cycle within a manufacturing plant. Purchase specifications may be rigid, inspection standards held high, and purchase prices maintained on a bedrock policy. Yet, as the material moves through the manufacturing cycle, this diligence begins to wane. The average factory worker and, in many cases, the department supervisors are seldom conscious of the value of the material being handled and processed. A continuous supply of large visible quantities of a given material tends to breed a natural laxity in concern over the damage or waste of a certain quantity here and there in the material flow through the plant.

Material specifications, prices, and inspection may be closely controlled, but the storing and handling of this same material are usually left exposed to loosely controlled hazards of damage, loss, and misappropriation. In most companies the handling of a few dollars in the petty cash box undergoes the utmost scrutiny. On the other hand, the handling of thousands of dollars of material is merely subjected to perfunctory inventory controls which tolerate blanket adjustments of many times the size of the entire petty cash fund without arousing proportionate concern over shortages. What plant manager would nonchalantly toss dollar bills around the floor of his plant? Yet in effect that is what is taking place every day, with the dollar bills in the form of materials out of control and also without adequate protection against shrinkage.

Storerooms in former days were little more than leftover spaces not required for production equipment. These spaces were usually located in areas found least desirable for other forms of occupancy. An illustration of this type of storeroom is given in Figure 111. Cubical space is utilized to a very minor extent; handling must be done mostly by hand; and material is easily mislaid, buried under other types of material, misappropriated, or lost. In such storerooms of yesteryear, little thought was given to storage capacities required, location of storerooms, or the influence of storage facilities on production efficiency and cost.

Utilization of Vertical Space

The customary practice today is to plan and design a storeroom along the same scientific lines employed in laying out a processing department. A complete analysis is made of all items to be stored, and suitable storage facilities are provided to accommodate these requirements. In contrast to the old-fashioned storeroom shown in Figure 111, a modern type of conventional storeroom for small parts is illustrated in Figure 112. Steel binnage utilizes vertical space to provide greater storage capacity and a definite orderly arrangement of stored items.

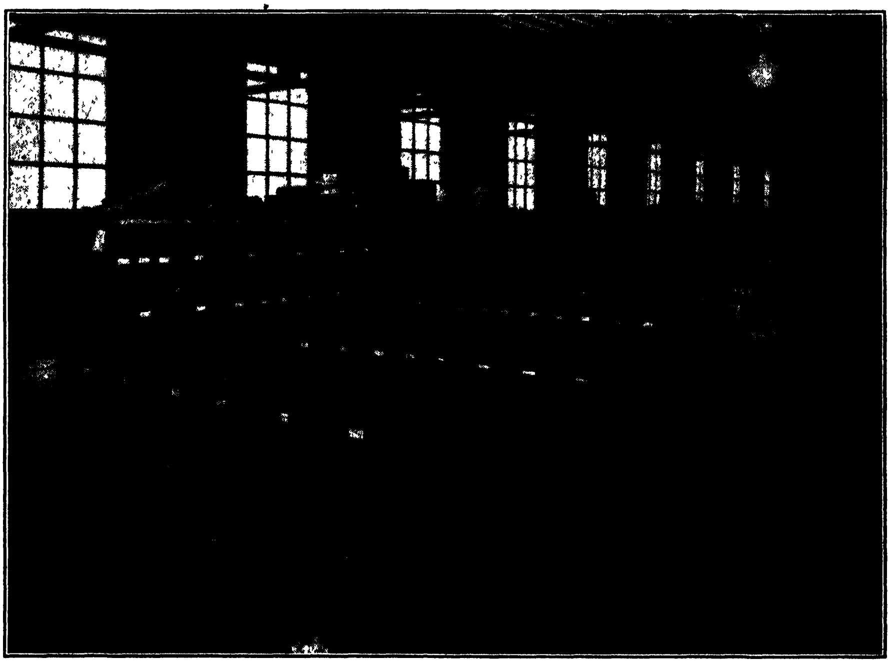


FIG. 111. *Wasted floor space.* Floor bins for storing hardware in a foundry. Vertical space, or "air rights," above the low-height floor bins is entirely unused. Valuable floor space is thus wholly taken up by knee-height bins in various degrees of disarray. These bins could be racked vertically to conserve the building area thus occupied. Stored material is poorly segregated, and much of it is virtually unprotected from misplacement and handling damage.

Where headroom permits, this type of storeroom arrangement can be doubled in capacity by the use of "double-height" binnage, that is, with an over-all height of 14 feet instead of the conventional height ranging from 7 to 9 feet. Such a storeroom is pictured in Figures 113 and 114. Through the use of double-height bins equipped with a steel grating attached at the 7-foot level, the storeroom area is made to accommodate a two-story instead of a one-story room under the same ceiling height.

Multiple-Functions of Storerooms

A storeroom is primarily a collection depot and reservoir for raw materials, worked materials, finished products, maintenance supplies, office supplies, small tools, etc. Depending upon its principal function a storeroom may be designated under a variety of names, such as stockroom, supply room, tool crib, dispatch station, raw stores, floor stock, yard storage, work-in-process storage, shipping stock, live or dead storage, stock pile, or reserve stock.

Material storerooms are principally reservoirs to keep the production lines adequately supplied with raw and semi-finished materials as required. These storerooms may supply either raw materials or semi-finished materials. They may serve as collection depots for materials partly processed in the plant and shipped out for further processing. In some plants, material storerooms are used as inspection points, and may also serve as accounting points for payroll calculations.

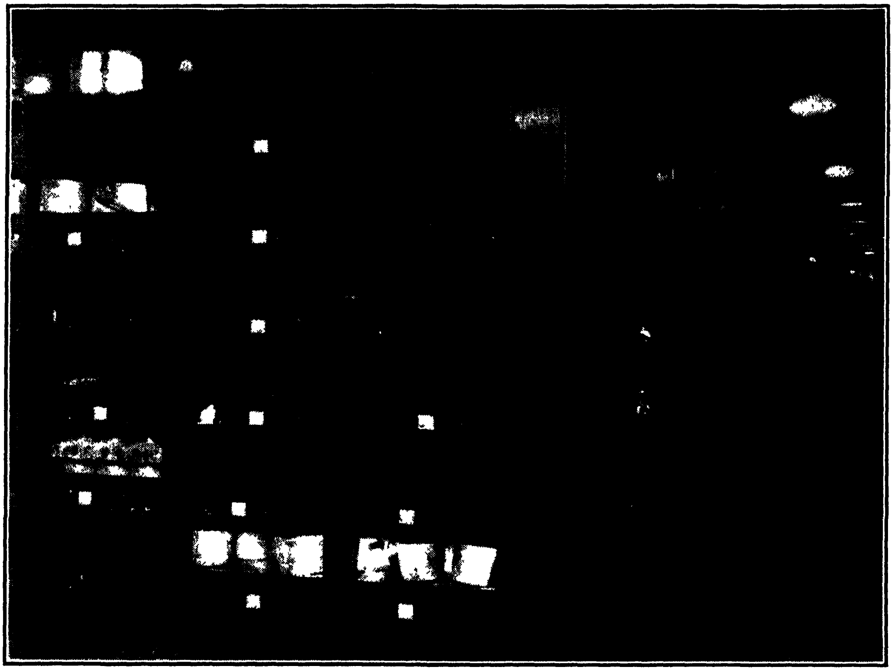


FIG. 112. *Economical utilization of floor space.* Conventional small-parts storeroom equipped with fixed type of steel binnage. Storage capacity over a given floor area is roughly 500 percent greater than the knee-height bins in Figure 111. Of even greater importance from the standpoint of operating cost, the storage, accessibility, and control of stock can thus be improved beyond calculable measure over disorganized floor storage.

Functional Basis for Laying Out a Storeroom

In determining the layout design of a storeroom, the following functional requirements are usually considered before undertaking a detailed study of the size and location of the storeroom:

FUNCTIONAL REQUIREMENTS OF STOREROOMS

1. **Protection** requirements for the material are dependent upon:
   a. Durability of the material.
   b. Its susceptibility to damage.

   c. Effect of climatic conditions.
   d. Exposure to losses through pilferage.

2. **Handling.** Special facilities required for handling and storing the material.
3. **Inventory control.** Degree of accuracy needed.
4. **Centralization.** Comparison of advantages of a large, centralized storeroom versus a series of smaller storerooms located at strategic points.
5. **Stores issues.** Operators calling at storerooms for materials versus delivery of materials to operators.
6. **Control point.** Desirability of designing the storeroom for joint use as a control point for material quality or cost accounting.

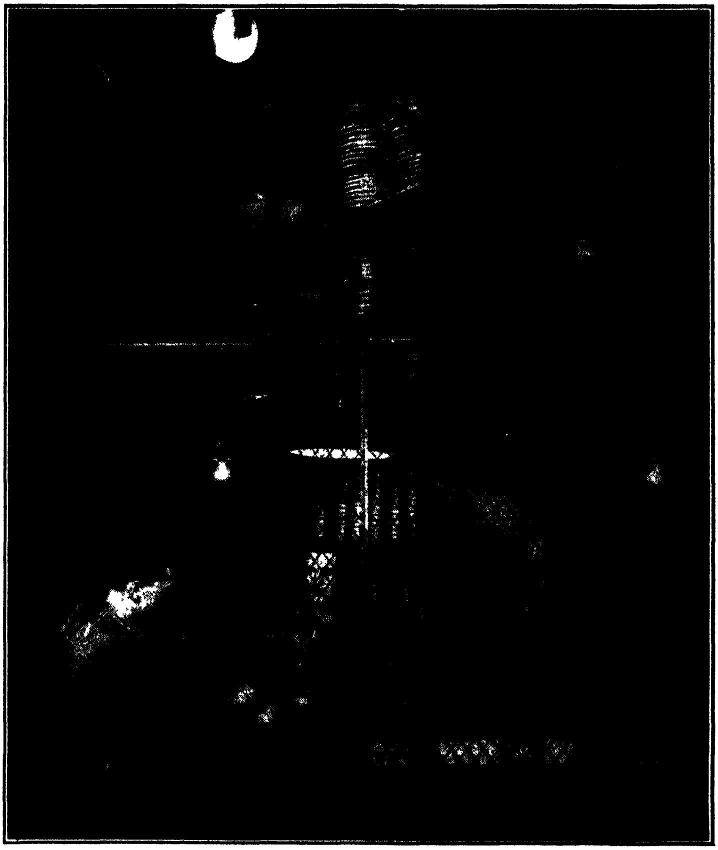


FIG. 113. *Double-height storeroom.* Through the use of double-height bins, this storeroom area has been converted into a two-story occupancy. The over-all height of bins is 14 feet, yet any bin is within arm's reach without the help of ladders or other movable device. The upper, or mezzanine, level is reached by a fixed stairway shown in the background in Figure 114.

If these functional requirements are ascertained in advance of designing the storerooms, much time and effort may be saved. Capacity requirements must next be determined before undertaking the laying out of the storerooms.

2. FACTORS FOR DETERMINING STORAGE REQUIREMENTS

The basis for determining the storage requirements for a storeroom depends principally upon the type of material or supplies stocked in the room. Capacity requirements for storing raw materials, for example, must take into consideration the following fundamentals:

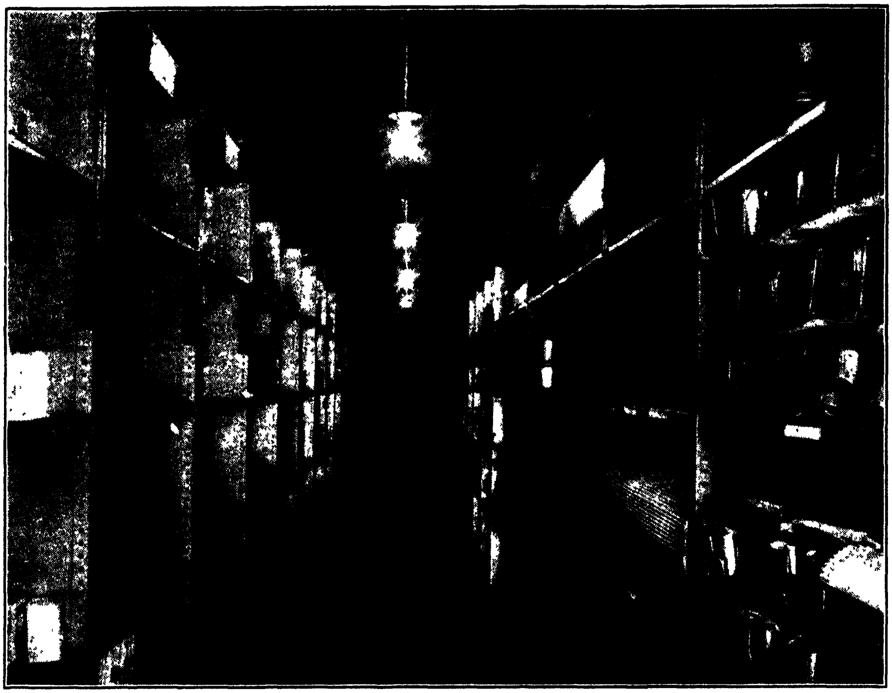


FIG. 114. *Mezzanine grating.* An overhead mezzanine grating attached to the bin stucture at the 7-foot level provides the aisle flooring for the upper tiers of the bins. Note that the interior of the bins has been painted white to improve the visibility of the stored items.

A. FACTORS OF SIZE AND FREQUENCY OF ISSUE

1. **Size of each item.** Size consists of length, width, height, and weight of an **individual piece.**
2. **Size of container.** Size consists of length, width, height, and weight of a **full container** in which the pieces are received.
3. **Number of pieces** in a **full container.**
4. **Frequency of issue.** Quantity of pieces required per year, month, and week, and representative number of pieces per issue.

Although these four fundamentals of size and frequency will determine the flexibility required to meet fluctuating requirements for storing raw materials, added consideration must be given to such factors as:

B. FACTORS OF MARKET CONDITIONS OF RAW MATERIALS

5. **Market availability.** Scarcity of the materials on the market, and length of period between purchase and delivery.
6. **Price fluctuations.** Storage requirements are influenced directly by price conditions on the market. During periods of rising prices stocks are frequently increased beyond frequency requirements, and are depleted when prices are falling.

FIG. 115. *Work-in-process movements.* Pallets of worked material dispatched by fork trucks from storage areas direct to machine operators. Operator in foreground is checking a move order against the pallet load in which it was received. Photograph taken at the Erie Works of the General Electric Company. (*Courtesy of the Electrical Industrial Truck Association.*)

Relationship to Productive Capacity

In the end, after all storage factors are considered, the capacity of the storeroom for any type of material, whether raw, worked, or finished, stems directly from its relation to the productive capacity of the plant. *A principal cause of interruption to production is the lack of needed materials at the time they are needed.* Although the delay occasioned by an individual item of material may not appear serious by itself, the collective number of such delays gives rise to much unnecessary cost in production. *The idle time of machine operators, extra setups, idle machine time, additional stock-chasing and production-expediting, plus numerous similar conditions, constitute in the aggregate a hidden load of wasted cost of operations.*

From the data developed in Chapter VIII in calculating the quantities to be manufactured and determining the capacities needed for the layout, it is but an additional step to determine the quantities of materials required to be stocked for this production. It is from these storage requirements that plans are developed for laying out suitable storerooms and floor storage areas, as illustrated in Figures 115 and 116.

Since most storeroom stocks are based on the frequency of their turnover, and turnover is dependent upon the production schedules in the plant, the size of the stock required of each material item becomes a straight mathematical calculation. Having thus determined the stock quantity of each material item to be stored and the frequency of its issue, the storage requirements for these items are developed from the additional factors enumerated below:

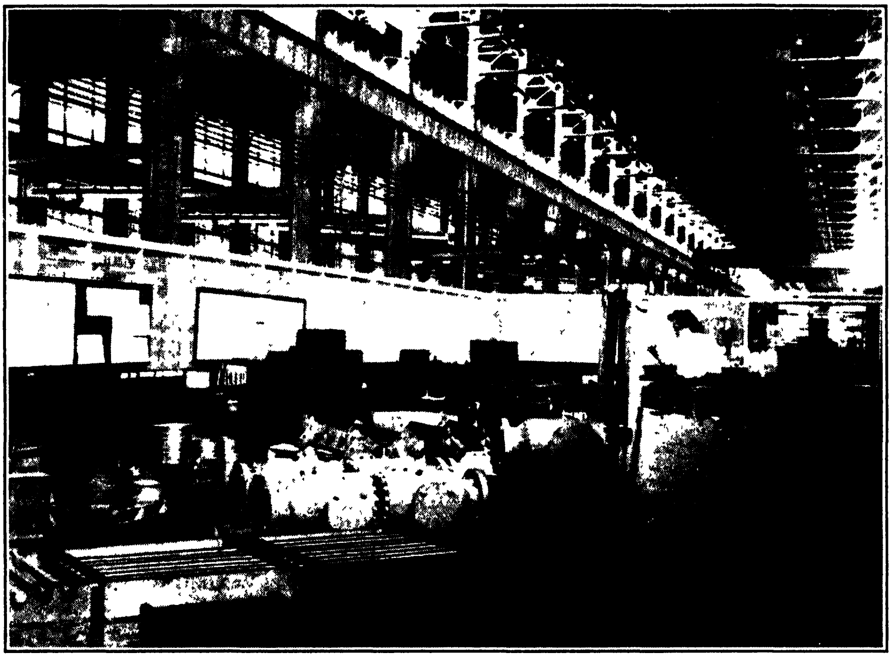


FIG. 116. *Work-in-process storage.* Pallets and skid boxes stored at a 45-degree angle to truck aisle. This type of storage insures instant accessibility and provides easy truck maneuverability into and out of storage area at the Erie Works of the General Electric Company. (*Courtesy of the Electric Industrial Truck Association.*)

C. FACTORS OF CAPACITY AND EQUIPMENT FOR RAW, WORKED, AND FINISHED STOCK

7. Maximum and minimum **quantities to be stored.**
8. Type, size, and **capacity** of binnage, racks, and shelving required in the storeroom.
9. If not stored in racks or bins, the **method of storing** to be used.
10. Degree of **protection** the material requires from the standpoint of safety against **fire, explosion, water damage,** etc.
11. **Method of handling** the material in and out of the storeroom.
12. **Inventory control** requirements.
13. **Protection** from **pilferage** and **waste.**

General Design and Location of the Storeroom

With these data properly compiled and correlated, the design of the storeroom may then be undertaken. In laying out the storeroom proper, two factors should be settled quickly before too many layout details have been developed. These factors are:

a. **General design** of the storeroom from a shape and cubage standpoint and
b. Approximate **geographic location** of the storeroom in the plant.

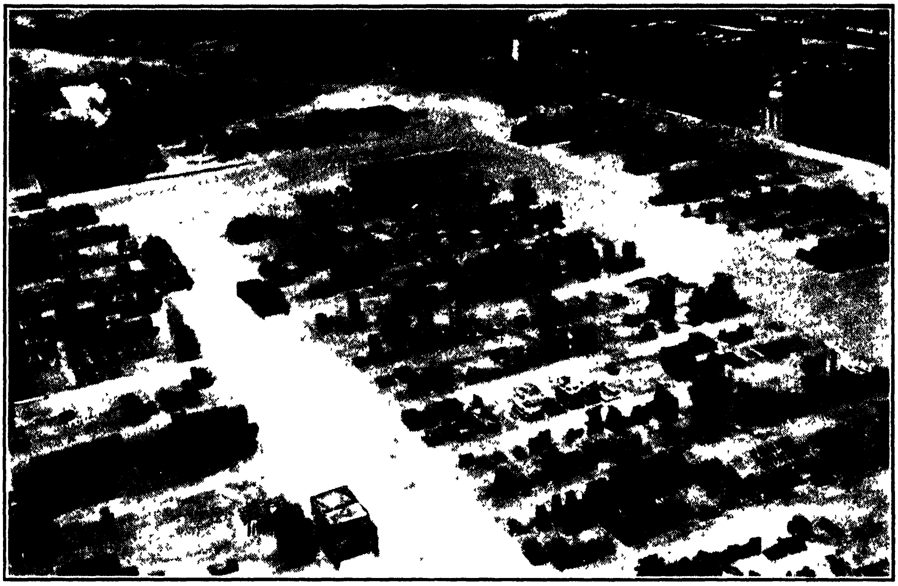


FIG. 117. *Outdoor storage area.* Freight-car siding has been depressed below ground level to bring car floor down to yard level. Width of roadways permits easy maneuvering of industrial trucks. Material has been so arranged that it can be readily identified, handled, and inventoried. (*Courtesy of Automatic Transportation Company, Chicago.*)

Either of these two factors may have a decided influence on the other. For example, if the location of the storeroom in the plant is a matter of prime importance, the structural limitations of the plant building may determine the shape and size of the storeroom. On the other hand, if the storeroom is laid out to an ideal design, this design may affect the selection of possible locations suitable to accommodate this storeroom.

Inventory Requirements

The need for periodic physical inventories adds to the storage problem, particularly when the count is frequent and the accuracy required is exacting. Inventory requirements thus have a distinct bearing on storage layout and handling methods.

Outdoor Storage

In determining the items that will withstand outside storage, consideration must be given to the effect of climatic conditions on these items. Some items may be stored fully exposed to the weather; others may have to be covered with a tarpaulin; and another type may require the shelter of a shed, etc. Typical of items which may be stored in the open are non-ferrous stock, painted stock, heavy rough castings, and material contained in drums and pails. Items that can withstand open storage when protected by tarpaulins or sheds include non-precision tools, equipment, hardware, material in wooden barrels, lumber, plumbing supplies, etc.

A view of a well-arranged outdoor storage area is given in Figure 117. With depressed trackage and wide roadways, this arrangement provides most of the advantages of an efficient warehouse layout. Visibility, accessibility, and ease of handling are all present. Only the protective shelter of the warehouse roof is missing, but it is unnecessary for the items stored in this area.

The layout of open storage space presents the same problems met in the warehouse, namely, the maximum utilization of stacking heights within the capacity of the mechanical equipment. It likewise requires easy access so that receipt, issue, and inventory operations can be carried out with a minimum of handling.

3. LAYING OUT STORAGE BINS, SHELVING, AND RACKS

Storing Pallet "Unit Loads"

Items that are too heavy and too large to be stored in bins are usually considered as a bulk-storage problem. Another type of bulk storage is found in the handling of items that may be stored on pallets, with the pallets stacked as "unit loads" one above the other, as many as five high. The vertical space above the 5-foot level is what has come to be commonly known as "air-rights." This space can be utilized for storage purposes through the growing use of fork-lift trucks. The space itself may be right beside the machines, on the loading platform, or in the warehouse. Its use adds to storage capacity and helps clear the aisles and loading platforms.

Bin Storage Items

Those items which can be stored in a bin because they can be handled, except in transportation, without the aid of mechanical devices, constitute in most plants the greater portion, by far, of all stored items. They frequently run into thousands, and tens of thousands, of pieces varying in size, weight, type, etc. In order to determine the best arrangement of bin space, three fundamentals must be considered:

a. Size of the piece.
b. Number of pieces in a standard container in which the pieces are received.
c. Frequency of issue.

Bin Storage Systems

In its search for the best basis for determining the binnage layout for storing the 250,000 different articles handled in a general-supply depot, the U.S. Army

Ordnance made an exhaustive survey of the following existing **industrial layout** practices. They consisted of:

1. Storing of material by **part-number sequence** in size groupings.
2. Storing of material together through the grouping of products of **specific manufacturers.**
3. Storing of material by grouping **like items.**

These storage systems were carefully studied and found wanting for the Army's stringent supply requirements. The practice finally adopted was based on the principle that storing of material in bins must be determined by **size and frequency of issue alone.** Practical experience has proved that the binning of material by size and frequency of issue meets the paramount need for flexibility.

Standard Bin Sizes

Because of the wide variety in piece size, the planning of bin storage involves a wide variety of bin arrangements. For the handling of over 250,000 different articles in a depot, the Army Ordnance provided bins in the standard sizes shown in Table 11.

TABLE 11. RANGE OF STANDARD BIN SIZES IN ARMY ORDNANCE DEPOTS

DESCRIPTION OF BIN	NUMBER OF OPENINGS	BIN SIZE Height	Width	Depth	WIDTH OF AISLE	DISTANCE TO SHIPPING ACTIVITIES
Smallest box type	84	6″	6″	12″	30″	Nearest
Largest box type	4	21″	36″	36″	36″	Farthest
Smallest rack type	21	12″	12″	72″	60″	Nearest
Largest rack type	4	21″	36″	36″	60″	Farthest

Standard Stock Racks

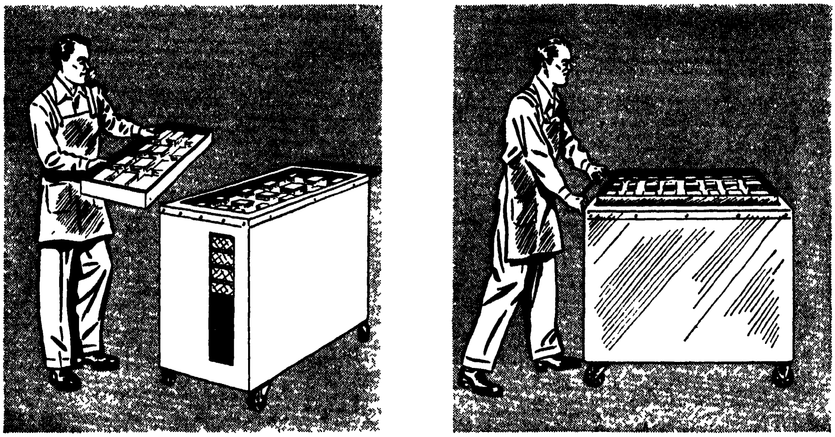
By way of comparison, the RCA Victor Division of Radio Corporation of America at Camden, N. J., has standardized its stock racks to the following storage unit. It may be joined together with other units, by tiering one unit on top of another to the desired height, and end to end to form a section of racks of any length within the requirements of the layout. The internal partitions of this standard-size stock rack may be arranged to any desired width and height to provide the suitable size and number of bin openings.

DESCRIPTION OF RACK	RACK SIZE Height	Length	Depth
Standard stock rack	42″	72″	18″

Storage at Work Stations

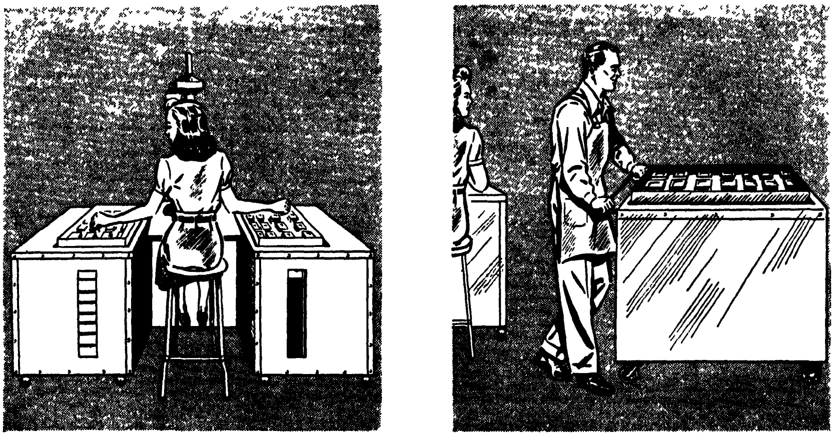
The problem of storing piece parts at a work station to await fabrication, while being processed, or after completion, has been handled fairly effectively through the medium of underbench stock racks designed to accommodate tote boxes and other types of parts containers used for transporting work in process. Facilities of this type, however, do not remove the physical back strain and accident factors inherent in the manual lifting of loaded tote boxes or materials from under the bench to the working level. This storage and handling problem at the work station has been eliminated through automatic material racks, such as the spring-powered type illustrated in Figure 118. This particular rack is on wheels, and therefore supplies its own means of transportation to and from the work station.

MECHANIZED STORAGE AT THE WORK STATION



A. Supply man loads rack with material to be processed.

B. Supply man wheels rack to work station.



C. At work station, material is constantly at table level in feeder rack (left) as well as in finished rack (right).

D. Supply man wheels away filled rack of processed material to next work station or into storage.

FIG. 118. *Automatic material rack.* Spring-powered rack which automatically raises and holds a visible bank of material constantly at operator's hand level in both the incoming and outgoing job lots. This rack performs the triple functions of (1) transportation, (2) material handling at the work station, and (3) storage. (*Courtesy of American Machine & Foundry Company, New York.*)

FIG. 119. *Adjustable rack,* quickly assembled to suit the requirements of the material to be stored. When these requirements change, the rack can be quickly dismantled and reassembled to dimensions needed. All sections and parts are standard and interchangeable.

FIG. 120. *Portable binnage.* The trays serving as bins are supported in structural frames which are mounted on caster-equipped bases. Each tray is removable, or the entire unit can be moved to the point of use. Trays can be handled either manually or by fork truck or overhead crane.

4. ADJUSTABLE AND PORTABLE RACKS AND BINS

Adjustable Skeleton Racks

The situation sometimes exists in which the type of material placed in storage dispenses with the necessity of providing bins in the storerooms. Frequently, skeleton-type storage racks are more suitable than bins for certain materials. These racks may be constructed from wood, piping, or structural steel. However, many types are difficult to dismantle and reassemble when the necessity arises to adjust them or move them to a different location.

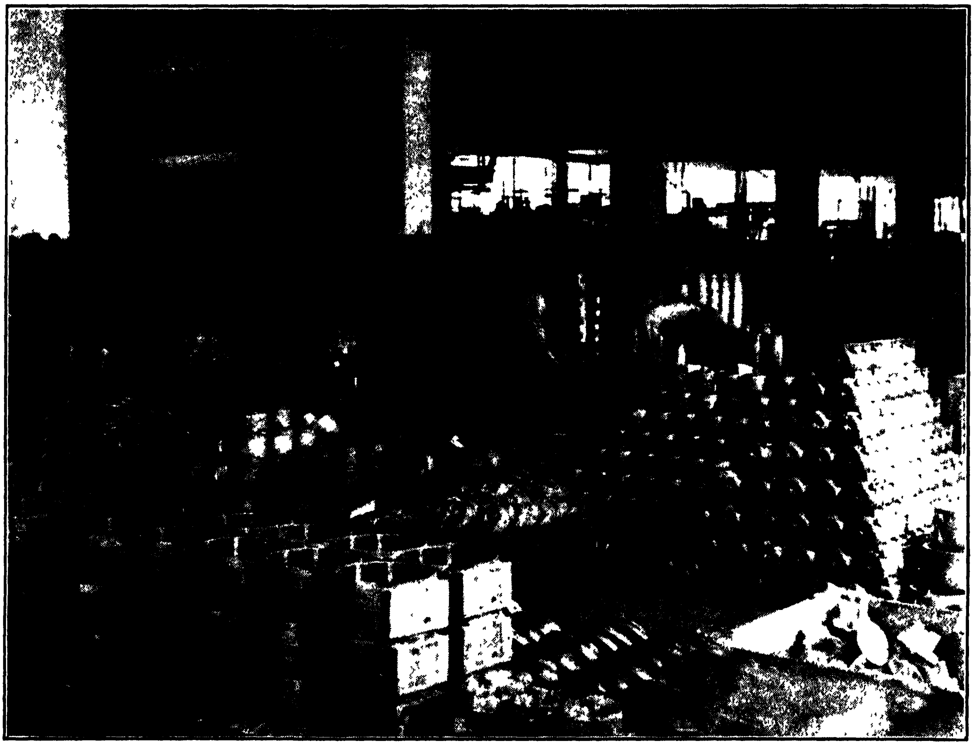


FIG. 121. *Piling material on the floor* is unquestionably the most expensive form of material handling. Each piece is individually picked up, moved, piled, unpiled, moved, and laid down in the material-handling cycle. Note waste of factory space above the pieces over which there is no piling.

Adjustable and portable racks that can be quickly fabricated and that also possess rigid structural strength are illustrated in Figure 119. These racks can be quickly assembled to meet specific storage requirements. They also lend themselves to quick dismantling and reassembling at other locations. Being made up of standard sections that are adjustable to desired dimensions, these racks offer unlimited flexibility in coping with changes in storage requirements. Flexibility in fixed bin racks is obtainable, however, as shown in Figure 114, through the medium of adjustable shelves which can be moved up or down to alter the heights of the bin openings.

Portable Bin Racks

In addition to the introduction of rotating bins, adjustable racks, and adjustable bins, a portable bin rack has been developed which has the effect of converting a storeroom into a mobile section of the plant. Through the medium of bin trays held in structural frames mounted on caster-equipped bases, as illustrated in Figure 120, the entire bin rack can be moved from the storeroom to the point where the stored material is to be used. These tray racks may be wheeled by pushing or handled mechanically by fork-lift trucks or overhead cranes, depending upon the weight of the filled rack and upon the distance traveled.

This movable multi-tiered rack can also be mounted on a skid to remove the mobility of the unit where easy shifting of units by unauthorized persons might lead to abuse. In this event, the trays themselves remain detachable and can be removed individually by hand as desired. If necessary, the trays can be affixed to the rack so as to prevent indiscriminate removal. In any event, should it become necessary to abandon the storeroom or to move it to another location, the entire room can be vacated in a matter of hours without involving any structural dismantling.

Tierable Containers

In some modern plants the tierable, or stacking, types of containers are used for storage purposes instead of more conventional binnage. Usually these containers are designed to interlock, permitting safe stacking to considerable height. Some of the larger units are handled by fork truck or crane and usually contain unit loads of material. This method of storing material insures flexibility and usually minimizes handling of individual parts.

CHAPTER XV

Test Areas, Inspection Points, and Dispatch Stations

1. PLANNING FOR QUALITY CONTROL IN THE LAYOUT

Necessity for Quality Control

The importance of making adequate provisions for controlling the quality of materials and products has received perhaps greater attention in the metal-working industries than in other types of intermittent manufacturing industries. This concentration may be attributed in part to the early start made in operation analysis, the cradle of quality control, by the metal trades. It is also due in part to the more rigid specifications required in machining metal parts on a mass-production scale for precision assembly into finished products.

The necessity for quality control had already received widespread recognition in several other industries before World War II. War contracts not only intensified the necessity for quality control but also made it a permanent institution in most industries, whether engaged on war products or civilian goods. The plant layout of today can therefore no longer be considered complete without due provision for quality control facilities.

When a plant layout has been designed to hold to a minimum the necessity for the inspection of materials in raw, worked, and finished stages, the layout plan correspondingly reduces the cost of policing material standards. While doing this, the layout also tends to provide a smoother flow of production unhampered by ill-timed or ill-placed interruptions to manufacturing operations because of inspection activities.

Important Factors of Quality Control

The functions of quality control are often construed as being limited to the following two:

1. Adhering to physical dimensions of a product to within the tolerances allowed over or under a given standard.
2. Reaching perfection of finish in a product.

Not only are these two goals only a start in the execution of quality control as it is applied in advanced industries today, but in some industries where quality control has been highly developed these two factors carry little or no significance. In such industries, other factors occupy the position of prime importance. For example, the quality control factor of predominant importance in chemical plants is the maintenance of consistency in process formulas. In packing houses, on the other hand, the paramount factors are the grading and health condition of the cattle to be slaughtered. Likewise, the lumber industry, glass industry, paper industry, etc., each has its own set of quality control factors for the materials and products it handles.

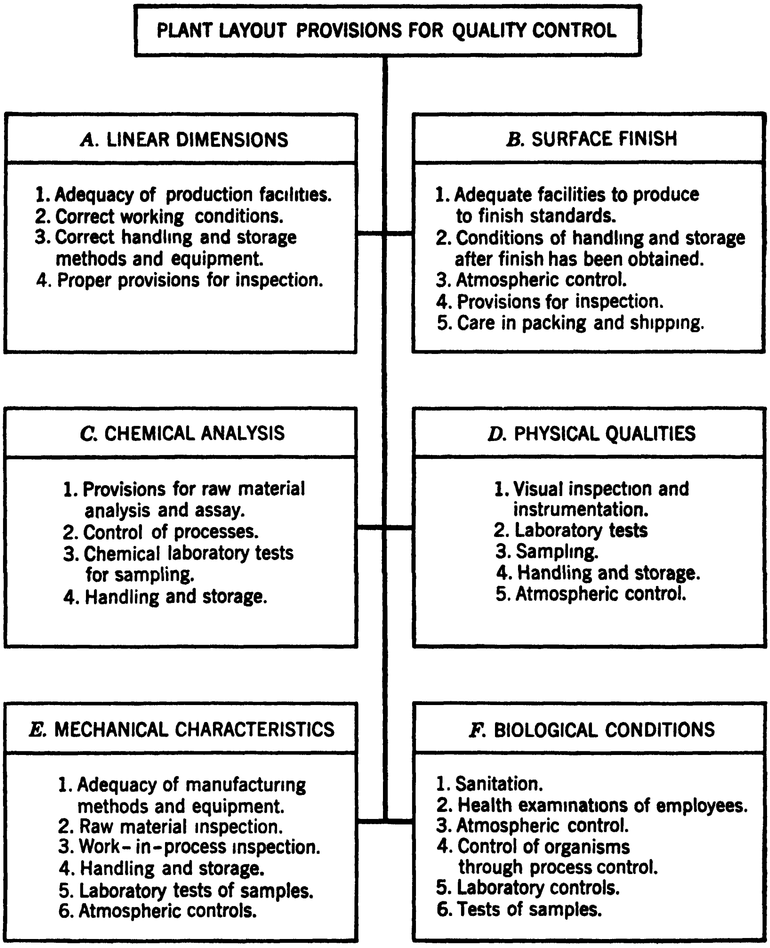

PLANT LAYOUT PROVISIONS FOR QUALITY CONTROL
A. LINEAR DIMENSIONS
1. Adequacy of production facilities.
2. Correct working conditions.
3. Correct handling and storage methods and equipment.
4. Proper provisions for inspection.
B. SURFACE FINISH
1. Adequate facilities to produce to finish standards.
2. Conditions of handling and storage after finish has been obtained.
3. Atmospheric control.
4. Provisions for inspection.
5. Care in packing and shipping.
C. CHEMICAL ANALYSIS
1. Provisions for raw material analysis and assay.
2. Control of processes.
3. Chemical laboratory tests for sampling.
4. Handling and storage.
D. PHYSICAL QUALITIES
1. Visual inspection and instrumentation.
2. Laboratory tests
3. Sampling.
4. Handling and storage.
5. Atmospheric control.
E. MECHANICAL CHARACTERISTICS
1. Adequacy of manufacturing methods and equipment.
2. Raw material inspection.
3. Work-in-process inspection.
4. Handling and storage.
5. Laboratory tests of samples.
6. Atmospheric controls.
F. BIOLOGICAL CONDITIONS
1. Sanitation.
2. Health examinations of employees.
3. Atmospheric control.
4. Control of organisms through process control.
5. Laboratory controls.
6. Tests of samples.

FIG. 122. *Effective quality control.* During the preliminary planning of a plant layout, a determination should be made of the provisions necessary to satisfy the conditions required. A synopsis of these provisions is contained in the chart shown above.

Provisions for Quality Control

The factors entering into quality control vary widely, of necessity, from industry to industry. During the preliminary planning of a plant layout a determination should be made of these factors and of the provisions necessary to satisfy the conditions required for effective quality control. A listing of the specific control factors to consider in each type of industry would extend beyond the scope of this book. A synopsis of the general provisions to explore in most manufacturing enterprises is presented in Figure 122. If the general factors outlined on this chart are closely investigated, the specific provisions to be made in the plant layout usually come to the surface during the course of the inquiry.

Obtaining quality by reworking a material in process is somewhat like locking the door after the horse is out of the barn. Preventive measures have taken the place of corrective measures in recent years. This movement is clearly expressed in the following slogan used by a leading manufacturer: "Quality must be built into a product; it cannot be inspected into it." It is through proper planning of the plant facilities and due provisions in the layout for quality control, rather than through remedial processing after the damage has been done, that the quality of materials and products is usually controlled most efficiently and economically.

Preventive Measures to Control Quality of Work

The majority of the layout provisions for quality control outlined in Figure 122 call for automatic execution of the control as an intrinsic part of the process or of the operating conditions rather than as a series of objective inspections. The general trend in the effort to "*build* quality *into* the product" is along the lines summarized below.

GENERAL PREVENTIVE MEASURES TO CONTROL THE QUALITY OF MATERIALS

1. Raw material inspection.
2. Suitable handling and storage facilities.
3. Modern building structures.
4. Good lighting.
5. Scientific color schemes in painting the plant.
6. Atmospheric control of dust, dirt, heat, and humidity.
7. Periodic health examinations of employees.
8. Adequate supply of measuring instruments for processes.
9. Laboratory testing of samples and the development of statistical controls.
10. Inspection stations located at strategic points along the flow of manufacturing processes.
11. Use of test floors.
12. Control over packaging and shipping methods.

Most of these preventive measures require definite provisions to be made in the plant layout. The logical time to make these provisions, as experience shows, is while the layout is being designed and not at a later time as an afterthought, to be squeezed in here and there, once the layout has been developed.

2. LAYOUT OF A RECEIVING-INSPECTION DEPARTMENT*

Planning for Quality Control

In capturing and holding markets for the finished products of a plant, the quality of the products is usually as important as the selling price. Often quality ranks above price in attracting and retaining sales markets. In the layout of a plant, therefore, **planning for quality control** becomes as important a fundamental as **planning for production.**

---

* Material for this section contributed by J. Manuele, Director of Quality Control, Westinghouse Electric Corp., East Pittsburgh, Pa.

The layout should be so arranged, however, that quality control can be obtained as a by-product of manufacturing activity, that is, at no additional cost over regular production cost. Getting something for nothing these days is undoubtedly as questionable as it is extraordinary, but it is a recognized fact that proper planning will accomplish helpful feats at no added cost over inadequate arrangements of plant facilities.

Prerequisites in a Receiving Department

The starting point in quality control is normally in the receiving department. Since the receiving of raw materials and purchased parts marks the first step in the manufacturing cycle, the layout must first provide for the place where, and the method by which, materials are received into the plant. The principal prerequisites for quality control in a receiving department usually include the following points.

PREREQUISITES FOR QUALITY CONTROL IN A RECEIVING DEPARTMENT

1. In order to make possible the proper inspection for quality and for conformity to specifications, it is essential that the receiving department be so located that all materials and purchased parts are **caused to pass through** this department.
2. The receiving area should be **fully enclosed** and separated from the flow in the rest of the plant in order to prevent the material from reaching the plant or storage areas until it has been properly inspected. The receiving department thus becomes a receiving-inspection area.
3. Since all material must pass through the receiving-inspection area, the layout of this area must provide for the efficient and **expeditious movement** of this material. Normally, material should pass through this area, from receipt to delivery, within one working day.

Receiving-Inspection Department

A typical combination receiving-inspection area is laid out on the floor plan shown in Figure 123. In this plan, the material is received by truck and rail and moves in a straight line from the receiving platform to the receiving floor, where receiving reports are filled out but withheld pending the signature of the material inspector. The receiving-inspection department is shown to the left of the receiving department.

Quarantine Area

All defective or rejected material or parts should be placed in a quarantine area until proper disposition has been made of these rejects. The quarantine area should be adjacent to, but not a part of, the receiving-inspection area. From this area, the rejected material might be disposed of by returning it to the supplier or by reconditioning it to bring it up to acceptable quality level. The quarantine area in Figure 123 is shown to the left of the receiving inspection department.

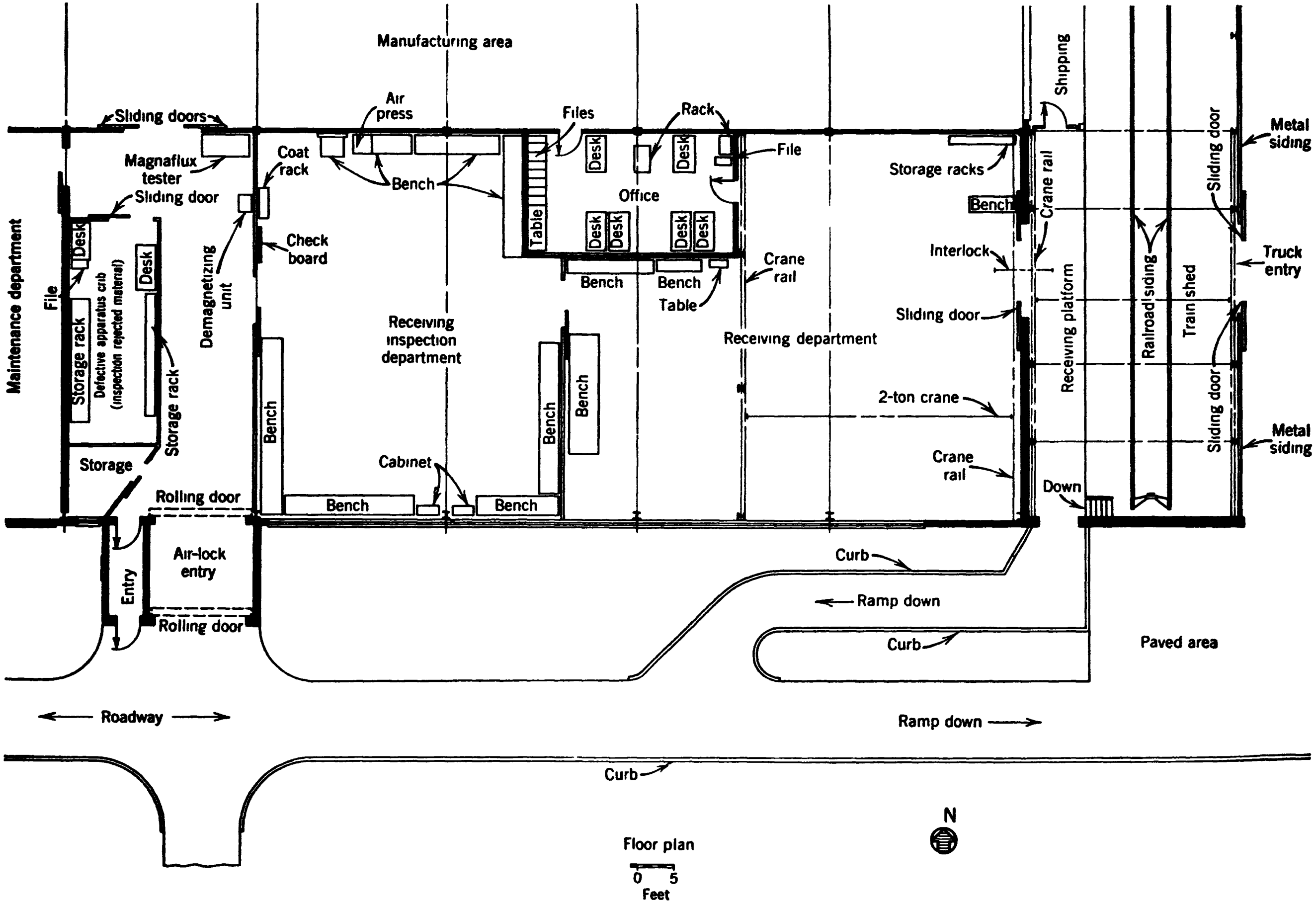


FIG. 123. Typical receiving and raw-material inspection department. (*Courtesy of Westinghouse Electric Corporation, Pittsburgh.*)

Three Component Areas for Receiving Activities

The layout of the receiving-inspection area shown in Figure 123 therefore consists of the following three component but separated areas:

1. Receiving department.
2. Receiving-inspection department.
3. Quarantine area.

Both the receiving-inspection and the quarantine areas should be included in the plant layout. Adequate floor space and suitable equipment should be allocated for these two areas at the time the plant layout is being designed. To do so after the layout has been installed would be but a makeshift expedient at the expense of the receiving department itself.

3. MODERNIZATION OF LABORATORIES AND GAUGE ROOMS

The location of the inspection department with regard to plant areas surrounding it or adjacent to it, is of particular importance, especially if the inspection department or laboratory contains sensitive inspection instruments. In designing the layout, care should be taken to avoid locating near the laboratory any manufacturing equipment that might cause vibrations in the laboratory instruments. A gauge laboratory, for example, should not be located in close proximity to a forge shop where heavy hammers might make the reading of delicate inspection instruments both erratic and difficult.

Old-Type Gauge Room

Gauge rooms in metal-working industries have undergone considerable modernization in late years. The features incorporated in modern gauge rooms necessitate special provisions in their layout. The old-type gauge room shown in Figure 124, where the then so-called "precision" instruments were calibrated and serviced, had but one distinctive feature, namely, isolation. It had no protection from vibration, heat, cold, humidity, dust, or dirt. Furthermore, it contained little or no provision for extremely accurate linear measurement.

Modernized Gauge Laboratory

The demands of industry for closer tolerances in mass-production plants has led to the introduction of new control features in the modern gauge laboratory, such as the one pictured in Figure 125. In this type of room, completely controlled atmospheric conditions are attainable. To properly maintain the measurement standards on a fixed basis, the room is held at a constant temperature. Humidity is kept constant and air pressure is kept slightly on the positive side, thereby causing an outward flow of air and providing a supply of clean air at all times.

Gauges are calibrated and precision measurements are concentrated in this laboratory. The walls are of salt-glazed tile, and the floor is covered with asphalt

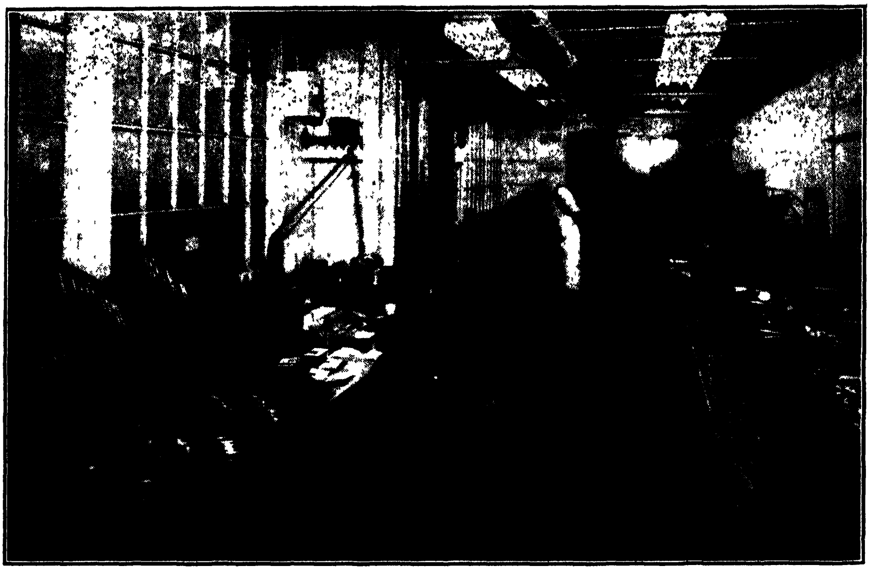


FIG. 124. *Old-style gauge room.* The construction of this room does not lend itself to the installation of atmospheric controls of humidity and temperatures. Instruments are confined mostly to physical-contact gauges not protected against expansion and contraction under various degrees of temperature. (*Courtesy of Westinghouse Electric Corporation, Pittsburgh.*)

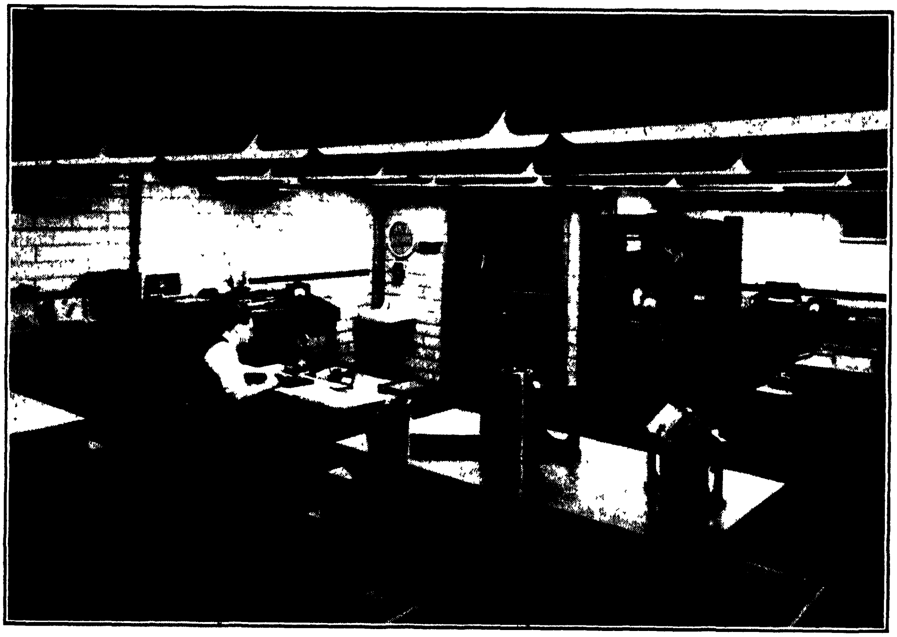


FIG. 125. *Modern gauge-control laboratory.* The humidity and temperature of the room are automatically controlled. Measuring devices include various types of electrophysical gauges protected from abnormal humidity and temperatures. (*Courtesy of Westinghouse Electric Corporation, Pittsburgh.*)

tile. The ceiling is made of sound-deadening material. Many plants have discovered that laboratory rooms constructed along these lines are not in the nature of an extravagance. They are but an advanced means of coping with the ever-mounting problem of guarding the quality of the product in order to attract and hold the markets that bring in the profits.

4. LOCATING INSPECTION POINTS IN THE PRODUCTION LINE *

Guarding against Damage in Material Handling

To prevent the production of defective units, close attention has to be given to the selection of proper manufacturing and handling facilities in planning a layout. The layout can contribute directly and in great measure to the attainment of a high uniform quality in the product by making adequate provisions to avoid damage to machined surfaces during transportation in the plant.

Line Storage to Eliminate Handling

Where conveyors are not feasible, line storage can contribute to product quality in several ways.

1. Line storage eliminates the handling of machined parts into and out of tote pans and boxes and piling parts on skids. The elimination of this handling automatically eliminates the incidental damage to finished surfaces.
2. Line storage also makes possible the proper "sampling" of lots for purposes of inspection and of quality evaluation. Sometimes line storage can be designed to permit inspection without actual handling of the parts.

Protecting Work in Process against Damage

Trucks or conveyors for the line storage of parts should be chosen with care. The size of the parts and the quantities to be handled should dictate the type of equipment to be selected. When trucks are used, due consideration should be given to the desirability of trucks moved by hand as against those using motive power. In all cases, the governing factor is the protection of parts in the following stages of processing: (1) during storage, (2) during movement between operations, and (3) during movement from operations to storerooms.

Very often, the plant layout engineer will plan a layout that is well-nigh perfect from the standpoint of flow of material. The handling or transportation of material between operations has been reduced to a minimum, and the flow of work through the shop is highly efficient. Yet he has failed to consider inspection stations and to provide suitable locations for these stations with respect to the flow of material and work in process between operations. Sometimes this omission is made deliberately in the interest of conserving floor space.

---

* Material for this section contributed by J. Manuele, Director of Quality Control, Westinghouse Electric Corp., East Pittsburgh, Pa.

Plant Layout Engineering and Quality Control

The plant layout engineer will seldom be called upon to determine the type and number of quality control points to be established in the layout. Decisions of this nature are usually made by the persons directly responsible for the control of quality in production. In many industries, this responsibility rests with the design engineering department. In other industries, the sales department may be vested with this responsibility. In still other industries, a committee functions for the purpose of exercising control over the quality of manufactured products. The general trend at present is towards the setting up of a central quality control department as part of the plant organization.

FIG. 126. *Inspection station in production line.* Exemplary inspection area properly planned and well laid out in the middle of the aisle it serves in a machining department. In addition to being equipped with an auxiliary jib crane, this station is also served by an overhead crane. The natural lighting is supplemented by local fluorescent fixtures that are swung over the inspection-surface plates and may be pivoted out of the way when parts are being lifted on or off the tables. (*Courtesy of Westinghouse Electric Corporation, Pittsburgh.*)

Because of the increasing importance of quality control, the plant layout engineer needs to be familiar with the basic principles of this activity in order to be qualified to plan inspection stations. To do this properly, he should understand the means by which the quality of products can be determined and maintained. He should also know what layout features should be engineered into the plant arrangement to help maintain quality at the lowest cost for the operation of quality control.

Locating Inspection Stations

For the adequate control of quality it is necessary that inspection stations be located so as to allow the parts to be given proper inspection at a strategic time during the manufacturing cycle, such as after definite operations have been performed. An inspection station ideally located for this purpose is shown in Figure 126.

Very often, the omission of inspection stations is not discovered until the layout design has been completed, the equipment has been installed, and production has actually begun. Under these circumstances, the inspection stations are hurriedly squeezed into whatever corner happens to be available, with utter disregard to proper lighting and ventilation. Sometimes even material-handling facilities are lacking.

Makeshift arrangements of this type increase the cost of handling parts to the inspection area. This increased cost, in turn, causes proper inspection to be slighted. The upshot of this train of events is that quality is allowed to deteriorate or costs of controlling quality are allowed to rise unnecessarily.

It is not always desirable to locate inspection stations "in the line." It might later be desirable to eliminate an inspection operation after proper control of product quality has been achieved. If an inspection station located in the line is thus later discontinued, valuable manufacturing space may be left idle. Consideration should therefore be given to the ultimate abandonment of an inspection station before locating it in the production line. Such a station must nevertheless be located where it will not affect the smooth flow of manufacturing operations.

5. PLANNING THE GENERAL ARRANGEMENT OF A TEST FLOOR

Test Floors as Proving Grounds

In heavy industries, such as in the field of machinery and electrical apparatus, test floors are frequently made an indispensable part of the layout. These floors are primarily used for studying the performance qualities, rather than the physical characteristics, of heavy apparatus before it is released for shipment to customers. A view of this type of apparatus and of the test floor on which the apparatus undergoes performance tests is shown in Figure 127. Very seldom are test floors used for the purpose of conducting destructive analytical tests such as are usually done in laboratory work. In contrast to destructive testing, test floors are used as proving grounds for the apparatus under inspection.

Not all heavy apparatus, however, can be effectively tested on test floors. Some extremely heavy apparatus, such as large hydroelectric generating equipment, cannot be properly tested elsewhere than in position under actual operating conditions. Builders of locomotives can test their product only on test tracks or in test runs "over the road." Automobiles are likewise tested away from the shop, over rough testing grounds.

Laying Out a Test Floor

The layout and design of test floors is a highly specialized task. The plant layout engineer should be capable of planning the general arrangement of a test floor, but the detail design should be executed by someone thoroughly familiar with the operation of the equipment required for conducting the tests. Practical experience in the use of this test equipment is of utmost importance in planning the arrangement of this equipment on the general layout of the test floor.

FIG. 127. *Testing performance qualities* of mechanical and electrical apparatus constitutes the primary purpose of a test floor. Instead of conducting destructive tests as is usually done in test laboratories, test floors are used as proving grounds of large apparatus before it is shipped to customers. (*Courtesy of Westinghouse Electric Corporation, Pittsburgh.*)

In actually laying out a test floor, the planning engineer must determine not only the number of pieces of apparatus that will be tested and the rate of flow of these pieces as they come off the assembly line, but also the physical dimensions of the test rigs. In plants which build specialized equipment to customers' orders, the test setups often become intricate and cumbersome.

For example, in testing the driving motor for a rolling mill, some practical means for testing the load capacity of the motor must be set up. Because the rolling mill itself obviously cannot be set up on the test floor, test engineers must resort to mechanical or electrical devices which will reproduce the load on the motor under actual driving conditions. Since the various types of conditions to be tested are not all foreseeable far in advance, the planning engineer must provide facilities for testing a wide and flexible range of probable conditions.

6. PRINCIPLES OF DISPATCH-STATION LAYOUT DESIGN

Controlling the Physical Flow of Material

In addition to areas set up for testing, inspecting, and controlling the quality of materials and products, areas are also set up for controlling the flow of these materials and products after they have been received and inspected. Such areas are designated as dispatch stations, and they have become increasingly popular in recent years. So long as material is in the course of being processed in the shop, it is not directly under control in regard to flow. Unless there is a positive means for following the movement of work in process, production bottlenecks may arise at unexpected times and thereby occasion costly interruptions in the flow of production.

It is still not uncommon in intermittent manufacturing industries to start material on the manufacturing cycle and then allow the material to remain in the shop regardless of whether it is being processed or not. In such cases, the entire control of the flow of material is solely dependent upon "paper work" in production scheduling rather than upon the physical control of the material itself. In theory, this form of movement control is intended to save material handling. In practice, however, as many a production manager will quickly acclaim, the strictly paper-control idea is usually a fertile source of production headaches.

Functions of the Dispatch Station

The evolution of the dispatch station has introduced a positive control in material movements in many plants. The principle of the dispatch station is to provide a conveniently located holding and matching point for physically controlling work in process and for storing it temporarily during pauses in the sequence of operations.

As illustrated in Figure 128, raw material is routed from storage to the first dispatch station, where it is doled out on production orders to a given number of process operations. From this point, the worked material is either routed on to the second dispatch station (if first operations have been completed) or returned to the first dispatch station (if work on first process operations has not been completed). In the latter situation, worked material is held in the first dispatch station until such time as it is scheduled for further processing in the first series of operations before being considered ready for release to the second dispatch station.

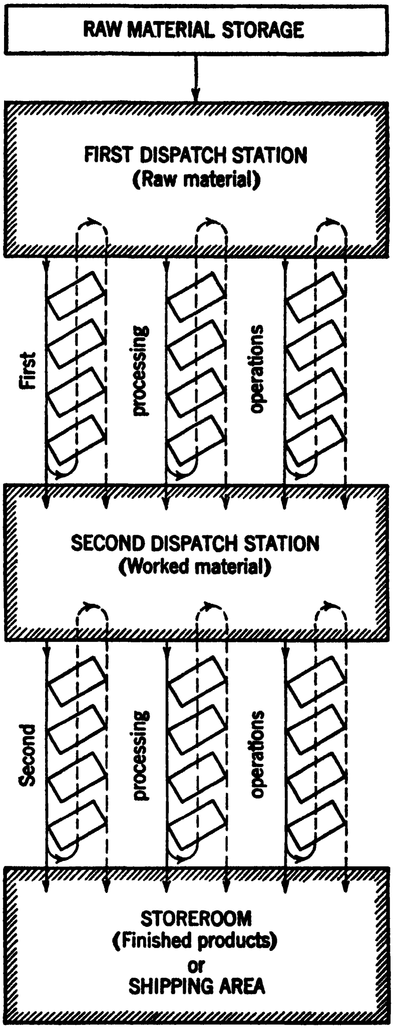


FIG. 128. *Dispatch-station layout design.* Raw material is routed from storage to first dispatch station, and from there to a given number of process operations. From thence it is either routed to second dispatch station or returned to first dispatch station to await completion of work in first processing operations. This cycle is repeated at each successive dispatch station until work is finished.

This cycle is repeated at each successive dispatch station until the worked material has finally been converted into finished products. When this stage has been reached in the manufacturing cycle, the finished products are released to either the finished-product storeroom or to the shipping area, depending upon the shipping schedule. At each move, therefore, the worked material passes through a physical control point where the work can be counted, inspected, held off the shop floor, and scheduled to the next processing point in quantities needed and in accordance with revised production schedules. This flow offers flexibility and smoothness of operation not attainable in hidebound paper work.

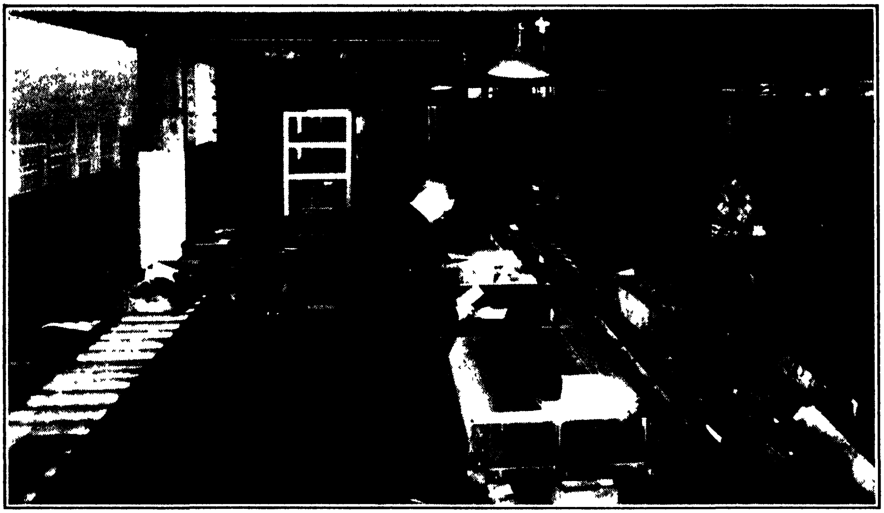


FIG. 129. *Mechanized dispatch station.* Control point of flow of material through a machining department processing a variety of small piece parts. All material is handled in tote pans traveling on a belt conveyor to and from the dispatch station. The upper level of the belt transports pans of material from the dispatch station directly to the machine operators' work stations. The lower level is used for returning the pans of completed material from the machine operators to the dispatch station. Material not being processed is held at the dispatch station instead of in the shop proper. (*Courtesy of Westinghouse Electric Corporation, Pittsburgh.*)

Floor Space Allotted for Operations

In planning and arranging operations for the plant layout, it is necessary to bear in mind that ordinarily the more excess space is allowed an operator, the less efficient he will become because of the increase in movements occasioned by the excess space. As a rule, the space for operations can be utilized more effectively if co-ordinated into a solid area rather than subdivided into a series of small, scattered work stations.

In the co-ordinated large area, the processing equipment is arranged with a minimum of machine clearances and of allowances for storing material in process. The operator is expected to remain at his work station while the work is brought to him for processing and is later removed from his work station when he has completed the processing operations on this work. The work is transported to and from work stations either manually or by means of mechanical handling equipment, depending upon the quantity of work involved and the frequency of its movement.

A Mechanized Dispatch Station

A dispatch station equipped with mechanical handling devices is shown in Figure 129. The dispatcher in this station has complete control over the flow of material in process. Only one job at a time is routed to each operator, and that job must be completed before another one is dispatched to the same operator. Material handling is entirely mechanized, and for this reason it is held at a minimum. Work orders, drawings, and other operation information accompany the material in the tote pan. This prevents the accumulation of material at the several work stations and keeps the material under planned handling and actual control at all times.

FIG. 130. *Combination storage and dispatch station.* Cartons are selected and transported by belt conveyors to the point of use, in quantities needed and exactly at the time required, on the floor below. The packing station is kept free of carton storage, and the packers' time spent in handling cartons has been reduced to a minimum. (*Courtesy of Westinghouse Electric Corporation, Pittsburgh.*)

Combination Storage and Dispatch Station

The same control principle can be applied to the handling of so-called "expense" materials, that is, materials not entering into the body of the product itself. Examples of expense material would include packing supplies and maintenance material. In Figure 130 is shown a dispatch station for storing and dispatching packing cartons. This particular station is located on the mezzanine floor directly above the packing area. When cartons are needed, the packer calls for them over a direct communication system. The dispatcher then selects the desired cartons and places them on a belt conveyor which carries them to the packing floor below and deposits them at the packer's station, all within the period of a few minutes. Handling is thus reduced to a minimum, and the control of stock is kept effective and real.

CHAPTER XVI

Maintenance Facilities, Tool Cribs, and Sprinkler Systems

1. PLANNING THE MAINTENANCE DEPARTMENT AND FACILITIES

Types of Repair Shops

Depending upon the type of industry, size of plant, and management policy towards the proportion of maintenance work performed by the plant force as against that farmed out on a contract basis, the nature and types of maintenance departments within a plant vary widely. Common to most plants are the machine shop, the electrical shop, and the tool crib. Additional repair shops found in various plants include carpentry shops, pipe-fitting shops, blacksmith shops. welding shops, paint shops, etc. These repair shops may be located in readily accessible sections of the factory building or may be housed in separate buildings of their own.

Locating the Maintenance Department

Before the depression of the 1930's, the maintenance department or departments in a plant were usually relegated to whatever space was left over in the plant layout after all production departments had been suitably located. With the cost consciousness brought about by the depression, the factor of maintenance costs began to take on added significance. Whereas a maintenance department had previously been generally regarded as but a "necessary evil," the mounting importance attached to maintenance costs literally lifted the repair shop "out of the cellar" and virtually placed it on a par with productive departments. Management was beginning to realize that each hour of production lost through delays in maintenance service due to improperly located repair shops was being dearly paid for in three ways, namely:

1. The time lost by the productive worker.
2. The output capacity lost on the manufacturing equipment.
3. The cost of making the repair.

Although it is recognized that productive operations (as shown in Figure 131) should be given the preferred locations in a plant layout, as dictated by the pattern of the flow of production, the maintenance departments must be located in sections readily accessible to the various operating departments of the plant, preferably near the hub of manufacturing activities. If a central maintenance department is being planned, its most advantageous location should be determined as soon as the various productive departments have been blocked out on the area allocation plan. When a number of decentralized maintenance departments appear preferable to a centralized one, studies should be undertaken to ascertain the geographic center of activity of each such department. Since maintenance is a service activity, much of the actual value of a service department is lost unless the department is so located that it can render that service quickly and effectively.

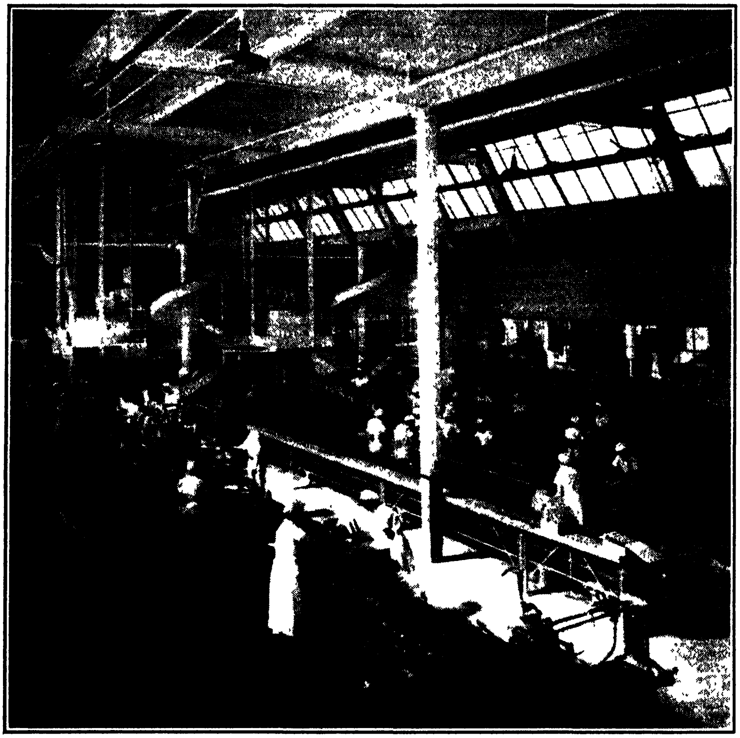


FIG. 131. *Face-powder filling department* in the cosmetic plant of Lady Esther, Clearing (Chicago), Ill. Atmosphere of immaculate cleanliness is enhanced by bright ceiling and walls and the white caps and uniforms worn by the women workers grouped along the conveyorized workbenches. Gravity chutes and glassed partitions will be noted in the background. (*Courtesy of Albert Kahn Associated Architects and Engineers, Detroit.*)

Some plants have found it desirable to adopt a compromise plan of central and submaintenance departments. Under this system, a fully equipped and manned central maintenance department is located in a focal point in the plant. Subdepartments are then located at strategic points throughout the plant where they can provide quick and effective service on minor repair jobs. These subdepartments operate under the supervision of the central department and draw on the central facilities and manpower to amplify their local maintenance work. This plan operates with particular effectiveness in large plants consisting of numerous buildings or of widely scattered layouts.

Classification of Maintenance Activities

Before planning a maintenance department, the plant layout engineer should acquaint himself thoroughly with the management policy regarding the performance of maintenance work. Some plants endeavor to do as much of the maintenance work as possible with their own plant force. The maintenance performed by a plant's own crews is commonly referred to as "captive" maintenance. Other plants prefer to contract, or "farm out," all but the minor repair work. To indicate the extent of "captive" maintenance work performed by maintenance departments in various plants, maintenance work has been classified into 14 major categories and distributed progressively over three classes of sizes of maintenance departments shown in Table 12.

TABLE 12. CLASSIFICATION OF MAINTENANCE DEPARTMENTS ACCORDING TO THE EXTENT OF MAINTENANCE WORK PERFORMED

MAJOR CATEGORIES OF MAINTENANCE WORK	CLASS 1 Subdepartment or Small Department	CLASS 2 Medium-Size Department	CLASS 3 Complete or Central Department
	A. BUILDINGS AND GROUNDS		
1. Maintenance of grounds.	Maintains only.	Maintains and improves.	Maintains and improves.
2. Construction of buildings.	No construction.	Minor construction.	Constructs buildings.
3. Alteration to buildings.	No alterations.	Minor alterations.	All alterations.
4. Repairs to buildings.	Minor repairs.	Minor repairs.	Complete rehabilitation.
5. Cleaning buildings.	No cleaning.	Daily cleaning only.	Complete cleaning.
	B. MACHINERY AND EQUIPMENT		
6 Installation of machinery and equipment.	Minor installations.	All installations.	All installations.
7. Overhaul of machinery and equipment.	Minor overhauls.	All repairs.	All repairs and renewals.
8. Transportation equipment.	No repairs.	Minor repairs.	All repairs and installations.
9. Fire equipment.	Inspects only.	Inspects and maintains.	Inspects, maintains, and installs.
10. Office equipment.	No repairs.	Minor repairs.	Most repairs.
	C. PLANT SERVICES		
11. Heating system.	Minor repairs.	Major repairs.	Major repairs and most installations.
12. Lighting and power.	No repairs.	Secondary wiring.	All wiring.
13. Communication systems.	No repairs.	Maintains.	Maintains and installs.
14. Painting service.	No painting.	Minor painting.	All painting.

Estimating the Size of the Maintenance Department

Before deciding on the size class into which a maintenance department should fall, the following determining factors should be carefully analyzed:

1. Estimate of annual cost of maintenance work done by the plant force and of the work performed on a contract basis.
2. Availability of maintenance trades in the plant locality.
3. Comparison of cost of "down time" losses in production versus the standby cost of keeping maintenance crews available for critical operations.
4. Effect on community and customer relations of captive maintenance work.
5. Availability of competent personnel in the plant for captive maintenance work.
6. Estimate of the amount of repetitive work in each type of maintenance trade. This forms the basis for determining the amount of justifiable captive maintenance in each trade.
7. Status of labor relations in the plant, and the contingency of jurisdictional disputes.

A thorough examination of these seven key considerations will assist in determining the portion and amount of maintenance work to be performed by the plant force. This estimate then becomes the basis for establishing the size of the proposed maintenance department. Not until the size of the department has been ascertained can the planning and layout of the department be undertaken with any degree of soundness or dependability.

2. FACTORS IN PLANNING AND LAYING OUT TOOL CRIBS

Insuring Availability of Small Tools

The storage, maintenance, and issuance of small tools constitute a plant service the major importance of which is not often fully realized. The dollar value of investment per cubic foot of space occupied by the department that performs these functions, namely, the tool crib, is usually many times that of corresponding space in any other section of the plant. Furthermore, all the scientific planning made in laying out machine tools becomes nullified without adequate planning for an uninterrupted supply of small tools in topnotch operating condition at the moment they are needed.

Much valuable machine-operating time can be lost each day while thousands of steps are taken by the machine operators in going to and from a crib to procure small tools. Additional valuable operating time can also be consumed by the operators in waiting at the serving window of the tool crib while the crib attendant walks around the various bin compartments looking for the needed small tools, or while the needed tools are being ground and reconditioned for use before being issued. Basic precepts of efficient tool-crib operation therefore require that not only must the right type of small tools be kept available in adequate supply, but also that the tools must be kept reconditioned at all times for instant use.

Types of Small Tools Stored in Tool Crib

The small tools stored and repaired in the tool crib consist of such items as cutting tools (reamers, drills, etc.), hammers, screw drivers, wrenches, air hammers, portable drills, tapping attachments, and soldering irons. In some plants, tool crib items include dies, milling fixtures, and drill jigs. Precision tools such as levels, calipers, micrometers, and bevel protractors are also usually kept in the tool cribs. The reconditioning of small tools includes sharpening, welding, grinding, checking for accuracy, etc.

In plants that operate a separate metal-stamping department, a special die-storage room is usually desirable near the presses. The aisles in this room should be wide enough to accommodate lift trucks. The shelving for die storage should be designed to hold the larger dies on lower shelves and the smaller dies on upper shelves.

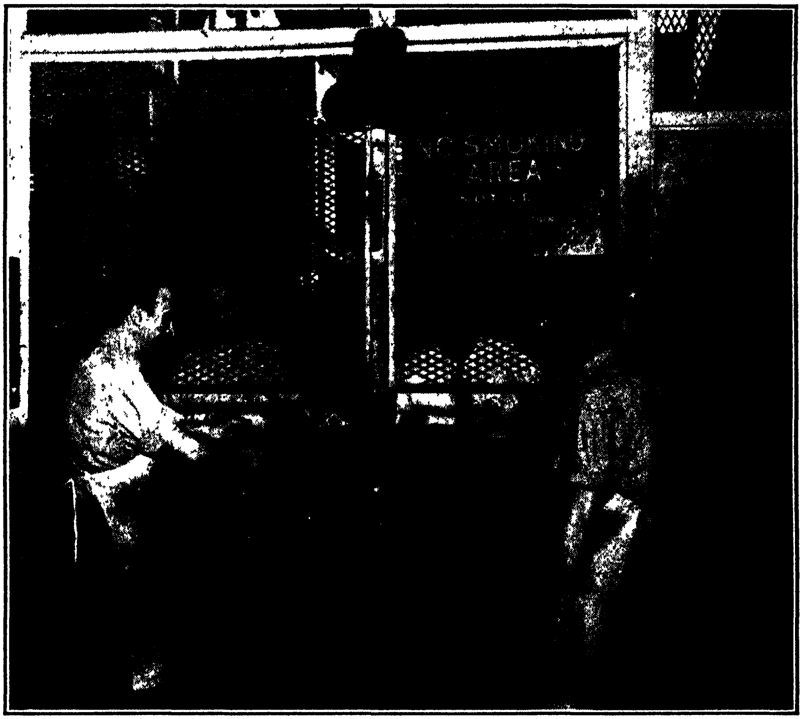


FIG. 132. *Old-fashioned tool crib* typified by dark area, cramped space, dingy appearance, small serving window, and congested storage.

The layout of a tool crib is based principally on the computations made for binnage and aisle-space requirements. The bin arrangement in a tool crib is laid out and identified in a simple way which permits immediate location of tools through storage designations such as:

Bin case 1, 2, 3, etc.
Bin A, B, C, etc.
Rack 1, 2, 3, etc.
Shelf A, B, C, etc.

Centralized Crib versus Chain Cribs

Before a plant layout is developed in detail, a decision must be reached as to whether the plant is to be served from a single large central crib or from a chain of small subcribs operated in conjunction with, and supplied by, a main crib. There is no fixed formula, other than economic considerations, for selecting one plan in preference to the other. Generally, small plants utilize the single-centralized-crib plan, whereas the larger plants find the main-crib system, together with its chain of subcribs, more advantageous. The three principal factors in determining which plan is the more favorable in a given plant are:

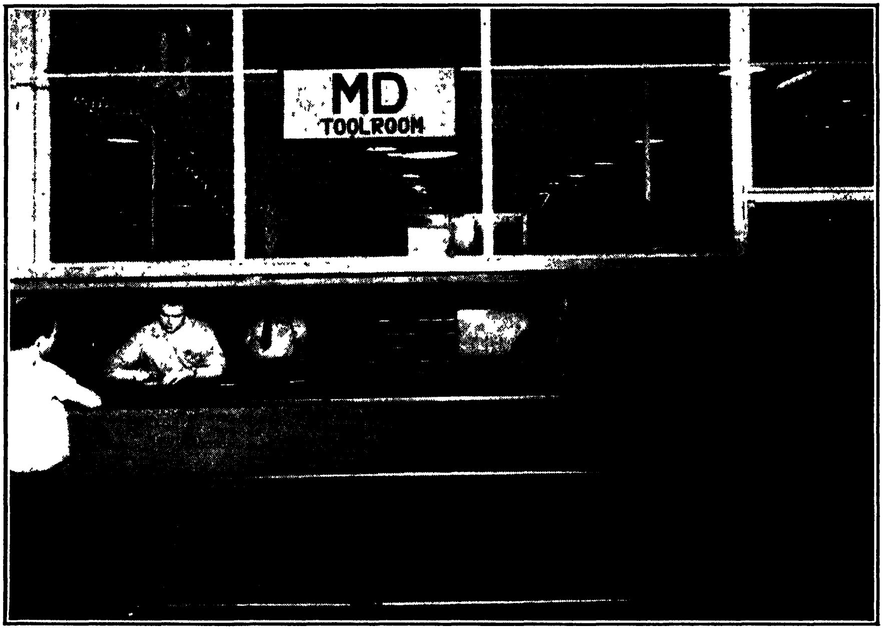


Fig. 133. *Modern tool crib* exemplified by convenient width and accessibility of its serving window. Guard rail protects workers at the window and regulates the flow of requisitions presented at the window The crib is well lighted and orderly in its bin arrangement. Tool control boards are located within easy reach of the window. (See Figure 134 for interior view of serving counter at this window.)

1. Walking time to and from the tool crib.
2. Waiting time at the serving window (see Figures 132, 133, and 134).
3. Additional cost of subcribs versus a centralized crib:
   - *a.* Increased inventory and duplication of tools.
   - *b.* Larger number of crib attendants.
   - *c.* More floor space, partitions, and binnage.

Locating and Planning Tool Cribs

Having decided on the type of tool-crib systems most suitable for the plant layout, the remaining factors to consider in locating and planning the tool crib are the following:

1. Locating the tool crib in the approximate center of operations to be served. This will minimize the walking time to the crib.

2. Laying out the tool crib to keep to a minimum the number of steps walked by the crib attendants in issuing tools at the serving window.
3. Designing the crib enclosure and binnage to protect the crib stock adequately.
4. Making provision for tool-repair equipment which will permit tools to be reconditioned quickly and properly.

FIG. 134. *Serving counter at tool-crib window.* Rotary binnage installed under the counter permits crib attendant to issue small items of frequent demand without having to leave the serving window.

5. Providing a tool-control system in the layout to show accurately the running inventory and charge-outs of each type of tool.
6. Allowing sufficient flexibility in the design of the tool crib to permit adjustment of crib facilities to changing conditions in manufacturing operations, such as expansion in production loads, changes in product design, etc.

All these common factors, plus a number of special ones which arise in different types of plants and industries, supply the basic data and conditions that influence the design of the detail layout of a tool crib.

3. PROVISIONS FOR THE RECONDITIONING OF SMALL TOOLS

Locating the Tool-Reconditioning Equipment

The normal wear and tear on cutting tools from usage in the shop necessitates a periodic reconditioning of these tools by expert operators. In some plants, tool grinders are located at strategic spots on the floor of the shop where the machine operators may conveniently grind their own tools instead of bringing them to the tool crib to be reconditioned. In places where expert operators can be entrusted with this operation, reconditioning on the floor saves much time for the operators of the machine tools located around these grinders. Other tool-reconditioning equipment may likewise be located at strategic points along the flow of production. Where the amount of time spent by machine operators in reconditioning their own tools on the shop floor exceeds the walking time required to go to a tool crib to exchange them for tools already reconditioned in the crib, it is usually more desirable and economical to have the tools serviced in the tool crib.

FIG. 135. *Tool-maintenance equipment.* Battery of tool grinders located in a tool crib. Grinder operators function as service-window attendants during peak periods. All cutting tools are inspected upon their being returned to the service window by the machine operators in the plant. Before being placed back into tool-crib stock, the tools are reground whenever they need it. (*Courtesy of Gaudreau, Rimbach & Associates, Pittsburgh.*)

Advantages of the Centralized Crib

In Figure 135 is shown a tool crib equipped with a battery of tool grinders. The advantages of a tool-crib layout of this kind may be summarized as follows:

a. Tools can be reconditioned whenever necessary, while the applicant waits at the service window.

b. All tools are properly inspected upon being returned to the tool crib and are reground before being returned into tool-crib stock. Under these conditions, the tools are always maintained in serviceable condition for instantaneous reissuance to the shop.

c. Grinder operators act as service-window attendants during peak periods of demands at the window.

d. This layout eliminates the cost of forwarding the tools to a location other than the crib whenever reconditioning is necessary.

e. It eliminates the need of carrying larger stocks of tools to allow for time in transit while the tools are being taken to another location for reconditioning.

Operation of the Chain-Crib System

When the chain-crib principle is employed in a plant, the reconditioning of tools is often confined to the main crib. As a rule, the subcribs do not have a sufficient demand for tool reconditioning to warrant the installation of tool-repair equipment. Like all rules, this one likewise has its exceptions. In the end, however, what governs the decision as to where the reconditioning work should be done, whether in a tool crib or on the shop floor, are the time element and relative cost involved.

4. LAYING OUT SPRINKLER SYSTEMS AND WATER SUPPLIES

Common Sources of Plant Fires

In addition to making provisions in the plant layout for maintenance facilities to guard the buildings, machinery, and equipment against deterioration from wear and tear, the layout must also include facilities for protecting the plant against damage from fire. Although fires may arise from faulty wiring, spontaneous combustion, and other sources attributable to the building structure, most plant fires stem from the occupancy of the buildings. These fires frequently result from carelessness on the part of the plant force or from hazards in process operations. For these reasons, the planning of protection against fire should take into consideration not only the features of the building design but also the probable number and type of operations in the plant buildings.

When planning the fire protection system or contemplating revisions to it, it is a good policy to consult the fire insurance carrier and local fire authorities. This service is usually available without charge, and many helpful suggestions can be obtained.

Operation of Sprinkler System

By far the most reliable and effective means of fire protection in a plant is the automatic sprinkler system. The sprinklers go into operation automatically soon after a fire breaks out. Each opened head wets the ceiling above it and deluges an area of approximately 100 square feet with a downpour greater than the heaviest rain. Operating in heat and smoke, the sprinklers control inaccessible or unseen fires that could not be reached effectively by other means. Unnecessary water damage is avoided because only those heads open that are needed, and all the water is used to good advantage.

Locating Sprinkler Heads

For reliable protection, sprinklers are needed wherever there is any appreciable amount of combustible material either in the building structure itself or in the occupancy it houses. In sprinkler-equipped buildings, sprinkler heads should be located not only on the ceiling, but also in closets, under wide benches, in driers, and in any area shielded from the discharge of the main sprinklers at the ceiling. High-temperature heads are needed near unit heaters, steam pipes, in some skylights and monitors, over heat-producing processes, in ovens and driers, and in similar locations.

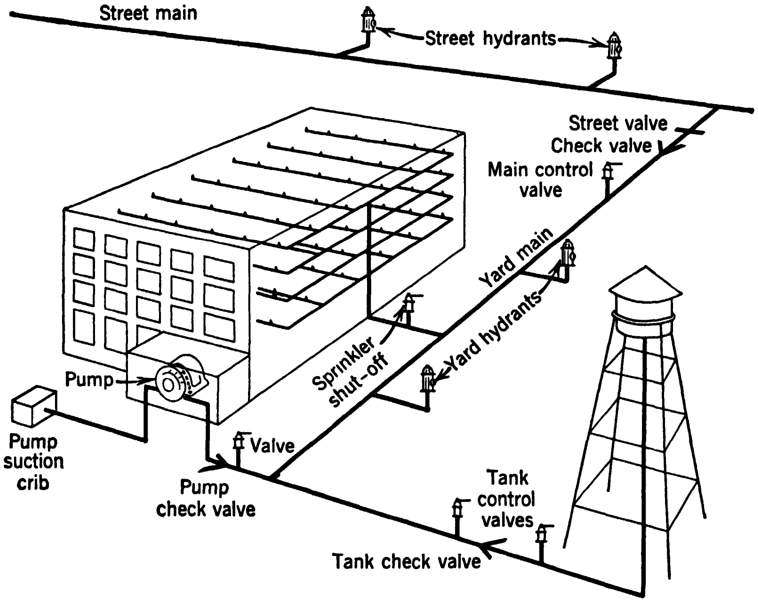


FIG. 136. *Layout of automatic sprinkler system* for an industrial property, showing primary and secondary water supplies, together with control valves and check valves. (*Courtesy of* Factory Management and Maintenance.)

Types of Sprinkler Systems

The most common sprinkler system is the **wet pipe,** wherein the piping is filled with water under pressure, which is immediately discharged when the sprinkler head operates, and continues to flow until shut off. The **dry-pipe** system is used where buildings are unheated and water in piping would freeze. The piping contains air under pressure which holds back the water at a dry-pipe valve in a heated location. When a sprinkler operates and releases air, the drop in air pressure automatically trips the dry-pipe valve and admits water to the system. The layout of an automatic sprinkler system for an industrial property is shown in Figure 136.

Sources of Water Supply

Most plants plan their fire protection to be independent of outside assistance. In addition to automatic sprinklers, provision is made for ample yard hydrants and hose equipment, reliable and adequate water supplies, good watchman service, and an organized fire brigade. Water supplies to automatic sprinklers and yard hydrants must be adequate both in pressure and capacity. Common sources are public water systems, gravity tanks, private gravity reservoirs, or fire pumps taking suction from rivers, ponds, or cisterns. Two or more independent water supplies are usually needed to guard against the crippling or exhaustion of one supply during a fire.

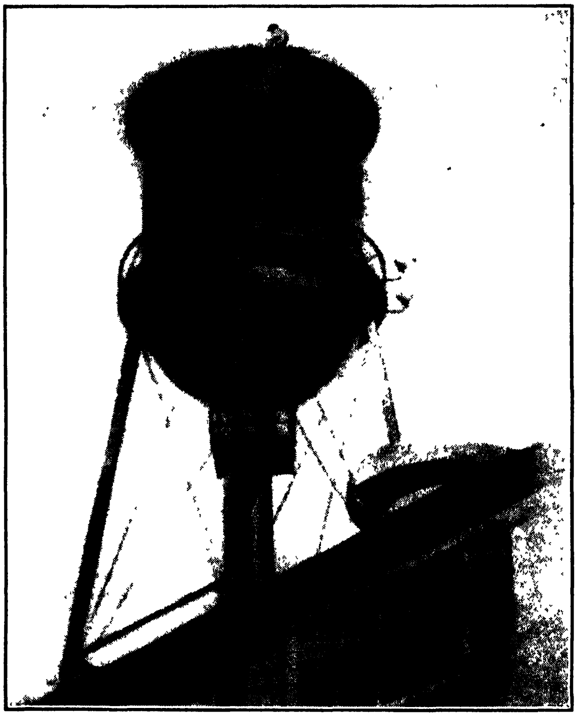


FIG. 137. *Gravity tank* elevated on a steel tower on the roof of a building.

Public water systems are the most common and usually the best primary supply through one or more connections to street mains of ample size fed by large distribution mains. Gravity tanks (see Figure 137) are used largely to supplement public water supplies where fire pumps are not feasible, or as a primary supply where a good public water system is not available. Gravity tanks are usually made of wood or steel and are elevated on steel towers or buildings. The 25,000-gallon tank is used mainly for the protection of small city properties and should be reserved for sprinklers only. The 50,000-, 75,000-, and 100,000-gallon tanks are used on larger properties as primary or secondary supplies of water for the sprinklers and yard hydrants.

The ideal arrangement of two independent gravity water supplies of ample **capacity** and **pressure** is seldom practicable. Therefore, a well-located fire pump, with ample suction supply and the capacity to maintain high pressure over a long period under most conditions, provides a satisfactory secondary supply. Centrifugal fire pumps of approved design are in common use. Practically all new installations use centrifugal pumps driven by electric motors, gasoline engines, or steam turbines. Most of the fire pumps installed are of the 1,000-gallon-per-minute capacity.

Use of Standpipe System

Next to automatic sprinkler equipment, a well-designed, -equipped, and -maintained standpipe system furnishes the best means of obtaining effective fire streams in the upper stories of high buildings. Standpipe outlets may be designed to supply the small hose streams used by the occupants of the building, or the large hose streams to be used by public or plant fire departments, or both sizes of hose. In buildings of unusual height, standpipes are sometimes supplied by a series of fire pumps and tanks.

Portable Extinguishers

In addition to major equipment such as the sprinkler system, fire pumps, and perhaps a fire truck, provision should be made for locating small portable extinguishers throughout the plant. Generally speaking, these are more effective for controlling small fires than are the sprinklers. Records show that small fires that are discovered and extinguished quickly are far more frequently experienced in industry than are the large fires requiring the use of major apparatus.

The portable units may be of the carbon-tetrachloride–soda-ash or carbon-dioxide type. The kind of hazard governs the type of extinguishing medium to be used. For electrical fires, it is important that the medium be a non-conductor. For oil or gasoline or similar materials, it is necessary to use a smothering type of extinguisher. In any of these cases, water would add to the hazard.

Quarters for Fire Equipment

Some plants maintain a volunteer or paid fire brigade, in which case quarters for the crew, as well as an equipment room must be provided. This is mostly true of large plants only. However, even small plants find it advantageous, from the standpoints of added protection and lower insurance premiums, to provide a small room where fire-fighting equipment can be kept and fire protection instructions can be given to a volunteer group.

CHAPTER XVII

Power and Lighting Systems *

1. OUTLINE OF FACTORY POWER-PLANT OPERATION

The design and installation of a power house for an industrial plant (see Figure 138) is a task for a trained power engineer. Likewise, the planning of electrical power distribution systems and lighting circuits in a plant calls for highly specialized engineering not within the scope of plant layout engineering. Yet plant layout influences, and is influenced by, the decisions made by these specialists. **The relationship of power-plant operation to plant layout** is concentrated principally on power drives, lighting systems, heating systems, and hot-water storage. A brief outline of the sequence and interdependence of activities within the factory boiler plant (see Figures 139 and 140) will pave the way for a subsequent consideration of laying out power-distribution systems, power-motor drives, lighting circuits, heating systems, etc.

SIGNIFICANT PRINCIPLES OF POWER-PLANT OPERATION

a. **Steam.** Practically every industrial establishment requires steam for all three of the following applications:

(1) Heating the factory buildings,
(2) Supplying hot water, and
(3) Providing heat for process operations.

This steam is commonly generated on the plant premises. The building space, power equipment, and distributing facilities necessary to generate steam entail a major capital investment.

b. **Electricity.** Every industrial establishment also has to have electrical energy, usually for all three of the following applications:

(1) Supplying power to run electric motors,
(2) Lighting the plant and process operations, and
(3) Heating, electrical furnaces, ovens, etc.

The problem of deciding whether it is cheaper to purchase this energy from a central utility service than to generate it on the premises as a by-product of steam production is a perennial question. There is no absolute scale against which any proposal can be checked. This is because in each case where a comparison is made, a new set of conditions is presented. The final evaluation depends almost entirely on the ability of the power engineer to determine and weigh the limiting factors.

---

* Material in this chapter has been edited by John F. Calhoun, assistant superintendent of electrical construction, Philadelphia Electric Co., Philadelphia, Pa., and Walter W. Wendelken, electrical superintendent, Westinghouse Electric Corp., East Pittsburgh, Pa.

As a general rule, when the demand for exhaust steam is small, it is cheaper to purchase electrical energy than to attempt to generate it in a steam plant on the factory premises. When the demand for steam in a plant is continuous and relatively heavy, the plant can frequently generate its own electric power more cheaply than it costs if purchased from a central station.

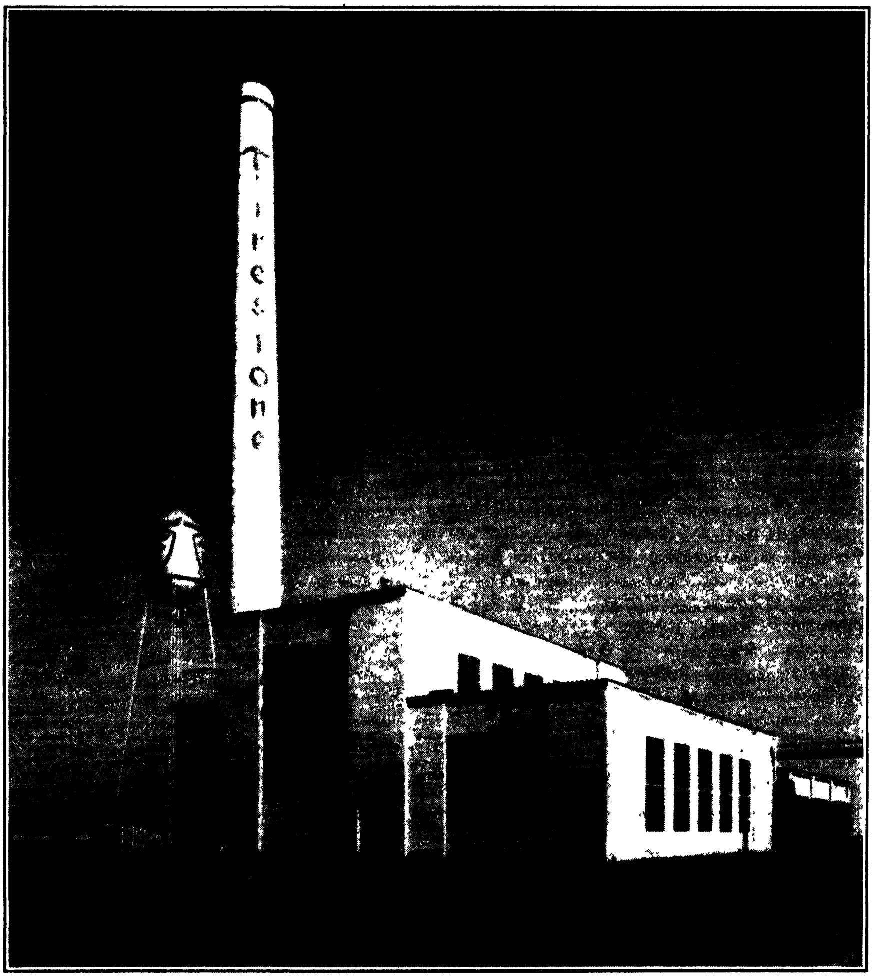


Fig. 138. *Factory power plant* of the Firestone Tire & Rubber Company, Los Angeles. This attractive building houses the boilers, air compressors, and other service equipment, as well as the switchgear controlling the electric power supply to the company's large manufacturing plant on the premises. (*Courtesy of Stone & Webster Engineering Corporation, Boston.*)

c. **Heat balance.** The common criterion governing the decision in favor of generating power on the plant premises is the "heat balance." When the live steam required to generate the needed electric power is just sufficient to provide an adequate supply of exhaust steam to satisfy the plant's requirements of low-pressure steam for heating the buildings, supplying hot water, and providing heat for process operations, a heat balance has been attained in the power plant. In this way, no exhaust steam has to be wasted in generating electric power. The condensate can be returned to the boiler for reuse in the heat cycle.

d. **Hot-water storage.** In plants where large quantities of hot water are used, a good heat balance may be usually maintained the year 'round by installing a large hot-water storage capacity.

e. **Exhaust-steam turbines.** The heat balance can frequently be also improved by the operation of an exhaust-steam turbine to drive one of the main generators. It may also serve as a supplementary power source for heavy, continuous, motor-driven loads.

f. **Diesel engines.** The Diesel-engine generating unit is frequently preferable to steam turbines in plants that do not require low-pressure steam and are outside of the area supplied by utilities. Diesel units produce no exhaust steam and operate with comparatively low fuel cost.

Differences in Power Plant

In summary, no two factory power plants are alike. Widely varying conditions of fuel, fuel costs, climate, cooling water, and plant requirements for low-pressure steam at various times throughout the year have a direct bearing on the results obtained from the powerhouse. These conditions make it advisable in some factories, and inadvisable in others, to generate a portion, or all, or perhaps none, of the electrical energy needed. In order to determine accurately the economies that govern a particular case, each plant should be studied as a separate problem.

Our concern in this treatise, however, is not so much with power-plant technicalities from a power engineering standpoint as it is with the distribution of power from a plant layout angle. Attention will accordingly be focused on the end results of power-plant operation insofar as it affects the layout of the distribution system, power drives, lighting circuits, heating facilities, and air-conditioning services.

2. LAYOUT OF ELECTRIC POWER-DISTRIBUTION SYSTEMS

Flow of Electrical Energy through the Plant

The power-distribution system in an industrial plant extends from the point of entrance of the power-company service (when purchased power is used) or from the plant generating station bus (when power is generated on the plant premises) to the terminals of the utilization devices or their controls. A flow chart of the elements encountered in laying out an electric power-distribution system is shown in Figure 142. The flow of electrical energy from the source of power through primary and secondary circuits is traced to the distribution panels at load centers on the plant layout. From this point the flow is continued through to the power drives and lighting systems, all of which are likewise incorporated in the plant layout.

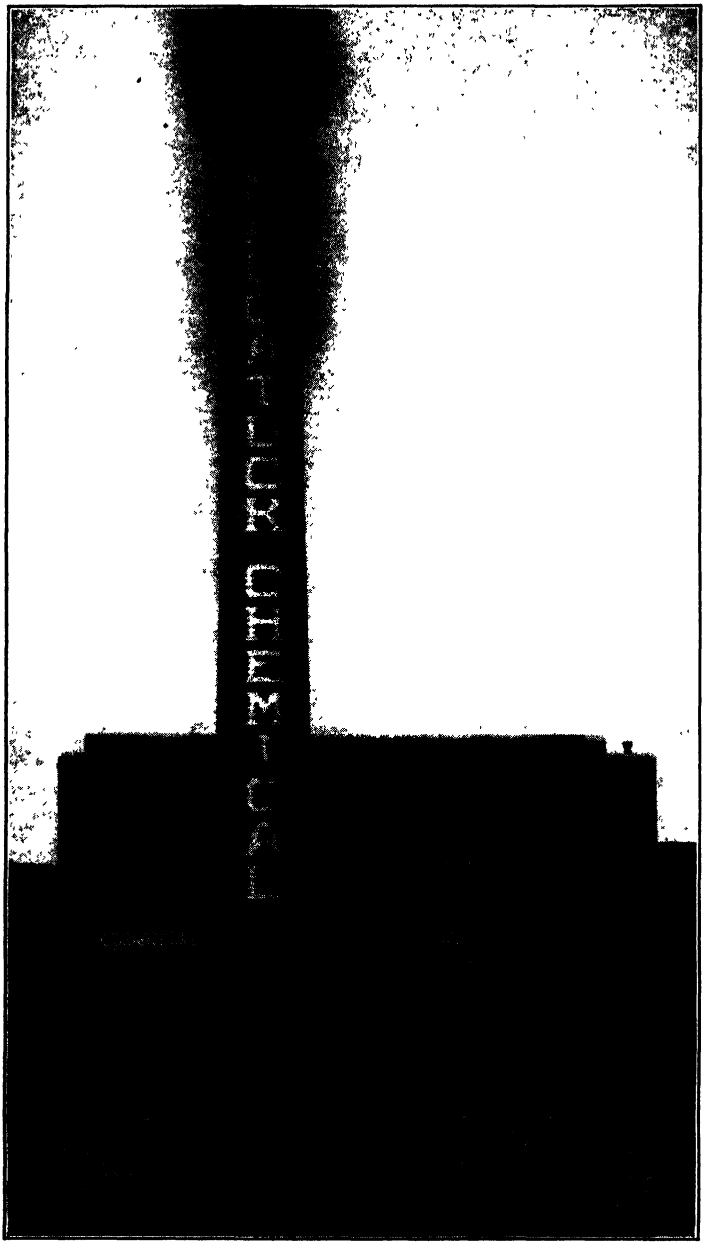


Fig. 139. *Factory power plant* of the Naugatuck Chemical Company, Naugatuck, Conn. Boiler house is 66 by 90 feet, with boilers on second story. Stack is 175 feet high. Elevation drawing appears in Figure 140. (*Courtesy of Lockwood Greene Engineers, Inc., New York.*)

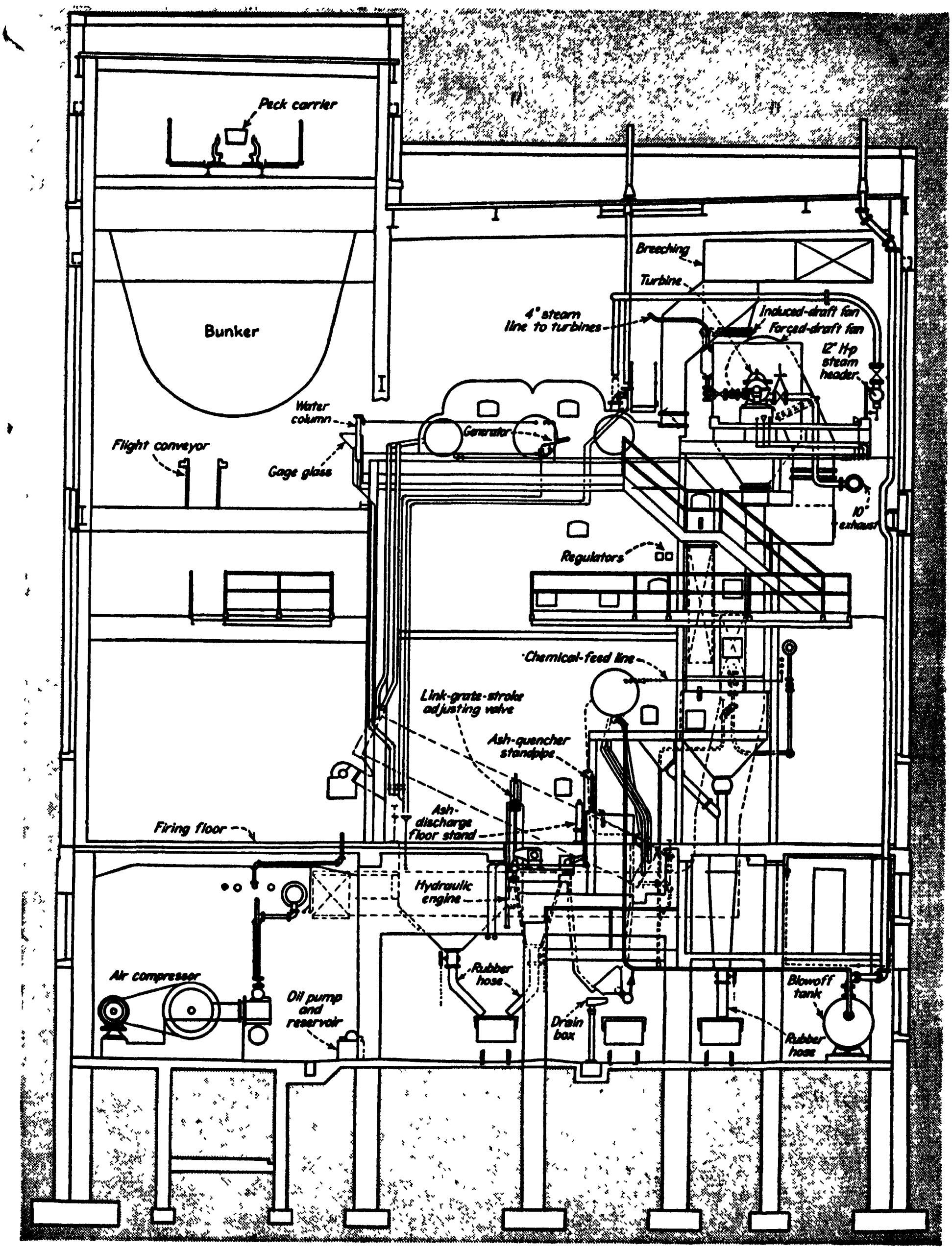


FIG. 140. *Cross-section of power plant.* Three boilers are fired by five-retort underfeed stokers. Normally, two boilers will carry the load. Boilers are on second story, about 18 feet above yard level. Economy in first cost was achieved by arrangement and compactness. See photograph of this power plant in Figure 139. (*Courtesy of Lockwood Greene Engineers, Inc., New York.*)

Components of an Electric Power System

An electric power system, like a mass-production assembly line or continuous flow process, is made up of components which must be closely linked to insure a well-balanced operation. Some of the more important points to be considered when designing a power system for a new factory or when modernizing an existing system in an old plant, are listed below:

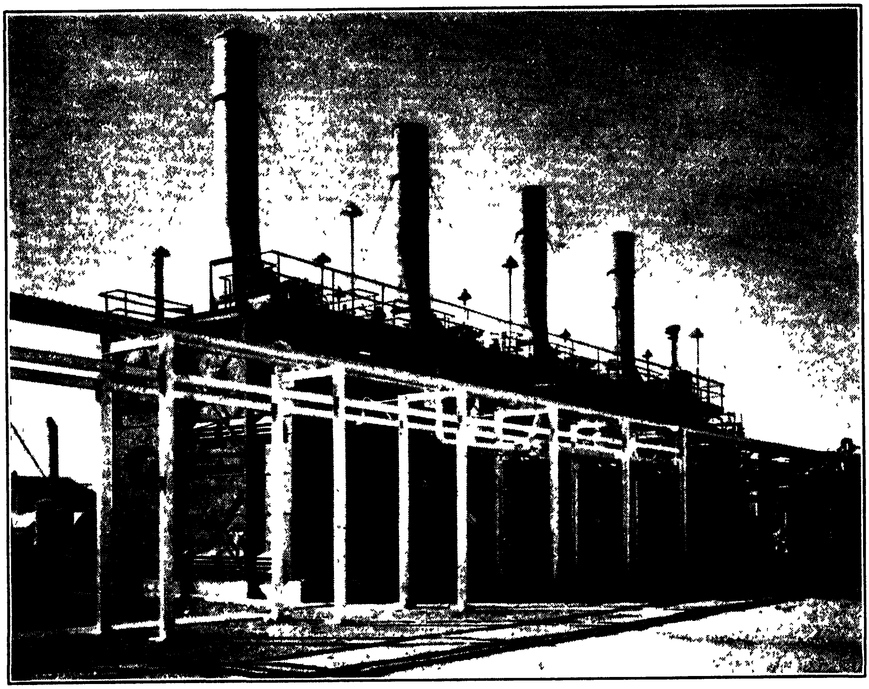


FIG. 141. *Outdoor boiler plant.* This installation for a chemical plant is completely out of doors. It is a striking example of the growing tendency to omit housing for steam, power, and other service equipment. (*Courtesy of Stone & Webster Engineering Corporation, Boston.*)

1. **Reliability of service.** Deciding on the desired limits of reliability calls for a careful analysis of the cost of total or partial shutdowns in manufacturing operations. This reliability, however, may be more important with certain kinds of equipment or processes than with others. When interruptions in the power supply must be avoided at all cost, it is advisable to provide duplicate power equipment or to obtain a reserve of power from a public utility. When an occasional shutdown will not cause serious trouble, however, there is little need to go to extra expense to guard against probable interruptions.
2. **Reserve for expansion.** Perhaps the greatest single error in industrial power-system planning is the failure to allow for load growth. The initial system should be installed with sufficient reserve for nominal load growth over the first few years and for expansion at any point in the plant.
3. **Flexibility.** Every plant rearrangement, or process change, alters the

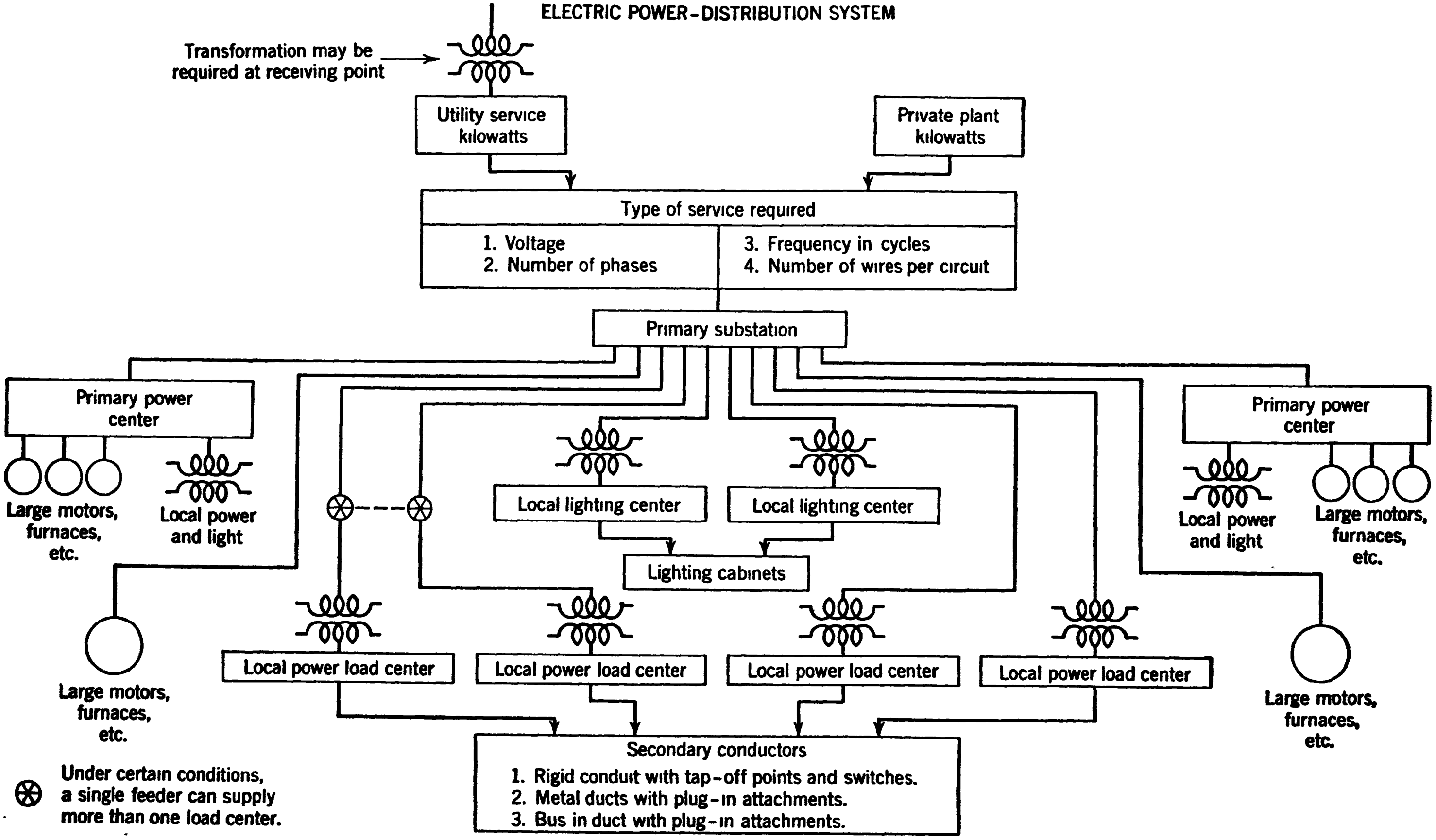

ELECTRIC POWER-DISTRIBUTION SYSTEM
Transformation may be required at receiving point
Utility service kilowatts
Private plant kilowatts
Type of service required
1. Voltage
2. Number of phases
3. Frequency in cycles
4. Number of wires per circuit
Primary substation
Primary power center
Large motors, furnaces, etc.
Local power and light
Primary power center
Local power and light
Large motors, furnaces, etc.
Local lighting center
Local lighting center
Lighting cabinets
Large motors, furnaces, etc.
Local power load center
Local power load center
Local power load center
Local power load center
Large motors, furnaces, etc.
Secondary conductors
1. Rigid conduit with tap-off points and switches.
2. Metal ducts with plug-in attachments.
3. Bus in duct with plug-in attachments.
⊗ Under certain conditions, a single feeder can supply more than one load center.

FIG. 142. *Electric power-distribution system.* Flow chart of elements encountered in laying out an electric power-distribution system in an industrial plant. (*Courtesy of John F. Calhoun, Assistant Superintendent of Electrical Construction, Philadelphia Electric Company.*)

electric load requirements. Inflexibility of the power system can be as restrictive to progress as are immovable partitions or machines. Provision for changes in plant layout and extensions to the plant, particularly in plants making frequent rearrangements of process machinery and equipment, is a necessity. This need is met by so-called flexible distribution systems comprising additional transformers, switchgear, bus bars, or cables carried in continuous metal ducts, with suitable provisions for tapping off or plugging into them.

4. **Maintenance facility.** An adequate system should include such design features as accessibility to perform maintenance on the major components of the switching and distribution units without interrupting plant operations. Circuit breakers should not be installed in extremely dirty atmospheres which would necessitate their frequent cleaning. Outdoor switchgear (of draw-out type) and transformers are very reliable and will not use up valuable building space. Switches can be operated from remote points. Maintenance facilities should be provided in the main building or in a separate building for this purpose.

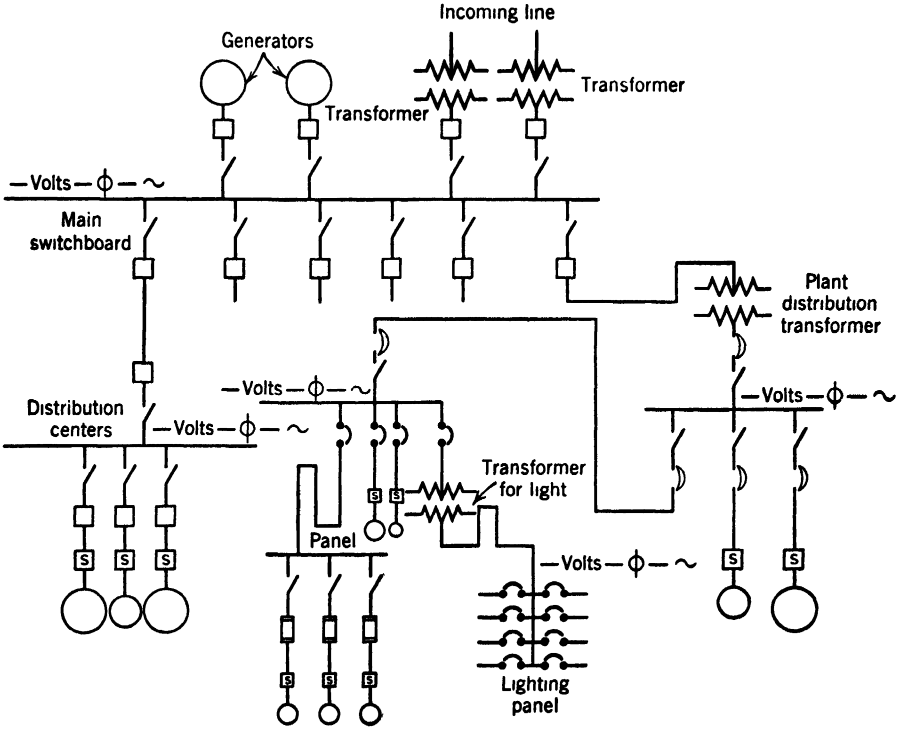


FIG. 143. *Typical single-line diagram.* Where details of complicated system connections are desired, simple schematic diagrams are preferred. (*Courtesy of Anaconda Wire and Cable Company.*)

Single-Line Diagram as Guide for Layouts

When planning an electric power system, the starting point is a single-line diagram of all parts of the system, from the source of power to the utilization machinery and equipment. A master plan in this form acts as a guide for making detailed layouts. A typical single-line diagram is shown in Figure 143, and the

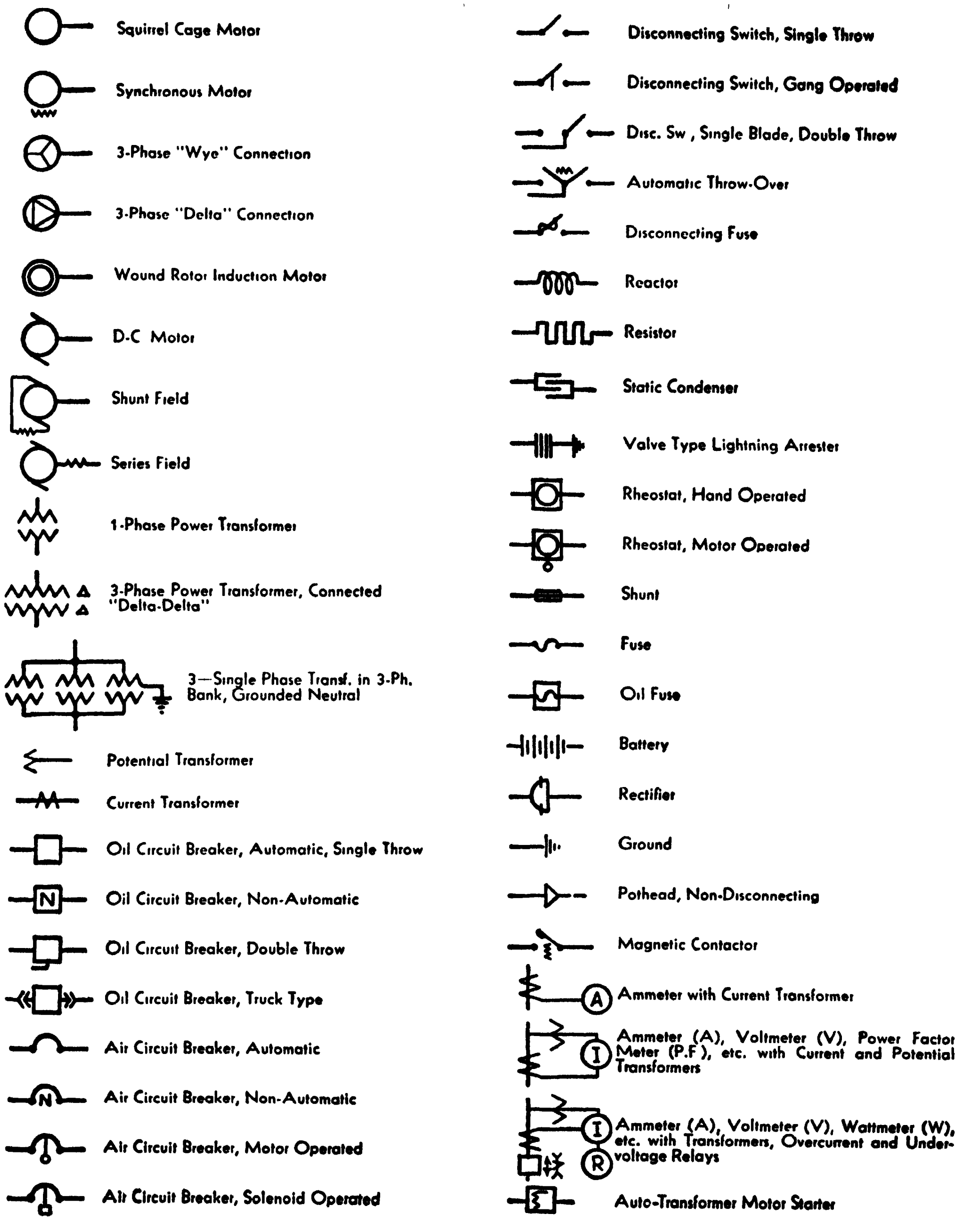

Squirrel Cage Motor
Synchronous Motor
3-Phase "Wye" Connection
3-Phase "Delta" Connection
Wound Rotor Induction Motor
D-C Motor
Shunt Field
Series Field
1-Phase Power Transformer
3-Phase Power Transformer, Connected "Delta-Delta"
3—Single Phase Transf. in 3-Ph. Bank, Grounded Neutral
Potential Transformer
Current Transformer
Oil Circuit Breaker, Automatic, Single Throw
N
Oil Circuit Breaker, Non-Automatic
Oil Circuit Breaker, Double Throw
Oil Circuit Breaker, Truck Type
Air Circuit Breaker, Automatic
N
Air Circuit Breaker, Non-Automatic
Air Circuit Breaker, Motor Operated
Air Circuit Breaker, Solenoid Operated
Disconnecting Switch, Single Throw
Disconnecting Switch, Gang Operated
Disc. Sw , Single Blade, Double Throw
Automatic Throw-Over
Disconnecting Fuse
Reactor
Resistor
Static Condenser
Valve Type Lightning Arrester
Rheostat, Hand Operated
Rheostat, Motor Operated
Shunt
Fuse
Oil Fuse
Battery
Rectifier
Ground
Pothead, Non-Disconnecting
Magnetic Contactor
A
Ammeter with Current Transformer
I
Ammeter (A), Voltmeter (V), Power Factor Meter (P.F.), etc. with Current and Potential Transformers
I
R
Ammeter (A), Voltmeter (V), Wattmeter (W), etc. with Transformers, Overcurrent and Under-voltage Relays
Auto-Transformer Motor Starter

FIG. 144. *Symbols* commonly used for single-line wiring diagrams.

symbols commonly used on such a diagram are described in Figure 144. Whether the power-distribution system is for a new plant or for the modernization of an existing plant, the preparation of a single-line diagram is considered the most indispensable first step. By means of such a diagram, alternate layouts can be analyzed for reliability of service, reserve for expansion, flexibility, maintenance facility, and cost.

Estimating the Power Load

Before this diagram can be made, the power requirements must be determined. The electric power system is then designed to fill these requirements. All possible data relative to the load in the proposed or existing plant must be assembled. By comparing the study of power requirements with the load in the existing plant, or that planned for the proposed plant, a sound basis is provided for designing the most suitable electric power system.

Unfortunately, not much information is available in technical literature to help designers estimate loads. However, some useful figures are given in the publication, "Electric Power Distribution for Industrial Plants," published by the Committee on Industrial Power Applications of the American Institute of Electric Engineers.

It is not practicable to select a number of substations and decide on their location until some idea of the load requirements has been obtained. It is usually necessary to know the rating of every motor and the demands of every electric device to be used in the plant. Satisfactory results may sometimes be obtained from load-density figures, that is, watts per square foot of floor area, required for various types of manufacturing processes. Power-supply conditions are changing at such a rapid pace, however, that it is generally better practice to analyze each problem on power and lighting requirements from actual or proposed usage for the particular plant under consideration.

After the initial load in the plant has been determined, the next most important step is to allow for future expansion. This allowance calls for more generating capacity or for a larger supply from the power company, and also for more switchgear and stepdown substations.

Load-Center Power Distribution

Modern practice in designing plant layouts before construction and then planning the structure around the plant layouts, provides an excellent opportunity for engineering load-center systems. Load-center power distribution, as illustrated in Figure 145, is set apart from other methods of delivery of electric energy to points of use within a plant by the following three distinctive features:

1. Power is received and distributed at high voltage (2.4 to 13.2 kv) to unit substations located close to the centers of electric load. Here it is used at the primary voltage or stepped down to utilization voltages, and delivered by short secondary feeders to the points of use.
2. When the total plant load cannot be met by a single substation, two or more load-center substations are used rather than a single one.
3. When flexibility and reliability are prime requirements, ties should be made between secondary sides of units. However, if such ties are used,

the cost of the installation is materially increased due to the necessity, in most cases, of installing higher interrupting capacity equipment.

Locating Substations and Feeders

It is advisable to check with the power engineer early in the planning stage so that location of substations and feeders can be planned as a part of the entire plant layout. Listed below are a few of the locations that have been chosen to keep secondary feeders short and to facilitate reclosing and inspection of circuit breakers without using valuable space:

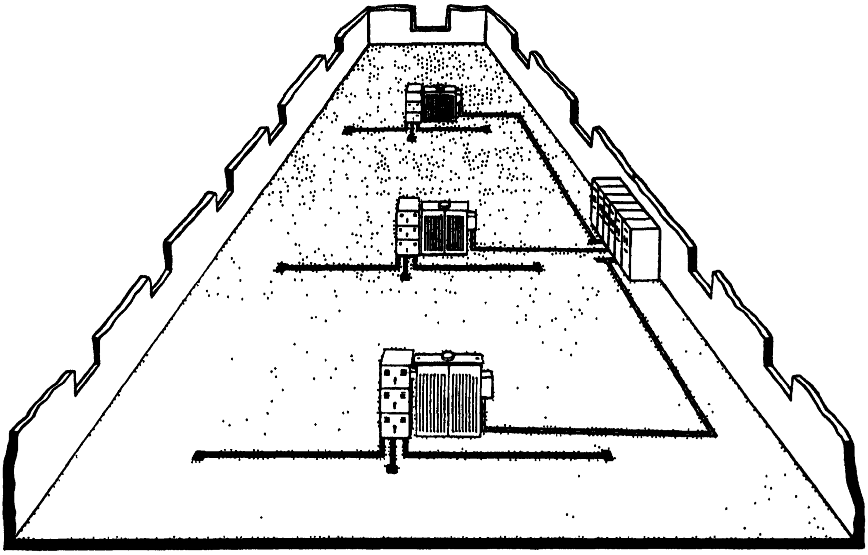


FIG. 145. *Layout* of load-center distribution.

a. On a long wall near the working area.
b. On balcony above the load center.
c. In basement under the production floor.
d. Outside the building and adjacent to the load area.
e. On the building roof or in the trusses.
f. On elevated platform close to the load.

With the advent of unit substations located near the working area, it has become imperative to use substations with all parts inclosed in grounded metal and with switching equipment of adequate interrupting capacity.

Transformer and Switchgear Equipment

The type of transformer and switchgear equipment used has a direct bearing on the layout and location of it. Either oil-cooled, air-cooled, or chemically cooled (Pyranol or Interteen) equipment may be used. In the event that oil-cooled transformers are used indoors, they must be housed in protected vaults.

For this reason, the general trend is toward air-cooled or chemically cooled 3-phase units. The higher cost of the latter type of equipment is generally offset by the lower building cost it entails.

Choice of Voltage

Many smaller plants are served directly from the utility line operating at 15 kv or less, depending on the load. In certain instances, the primary voltage can be used for distribution to the load-center unit substations within the plant. On others, the voltage can be stepped down at the point of entrance and transmitted at lower voltage to unit substations in the plant.

The choice of voltage is determined by the power company from the load requirements developed by the designing engineer. When large blocks of power are required, the utility company may supply the need at voltages above 15 kv. It is generally conceded that higher voltages should not be taken into the plant because of the excessive cost for building and equipment necessitated by these voltages. Therefore, transformation is required from the higher utility voltage to the primary voltage in an outdoor-type of substation from which power is fed directly to substations located at the load centers. By far the most commonly used voltage for power equipment of 200 hp or less is 460/230/115 volts, 3-phase.

3. SELECTION AND LAYOUT OF POWER-MOTOR DRIVES

The transmission of power from the prime mover, usually an electric motor, to the driven machines, either by direct connection or through speed-reducers, lineshafts, countershafts, belts, chains, gears, etc., constitutes a fundamental factor in plant arrangement. The type of motor drive selected for the machines either influences, or is influenced by, the arrangement of the machinery in the plant layout and the installation of overhead equipment, such as cranes and conveyors, in the space above the machines.

Preceding the introduction of the electric motor, the steam engine was the common prime mover of industrial machinery. Because of the comparatively large size and high investment cost of the steam engine, a plant seldom had more than one of them. Power was transmitted from this engine to the various driven machines through the medium of lineshafts, pulleys, and belts. When the steam engine was first replaced by the electric motor, a single motor was used to operate the lineshaft system. This driveshaft arrangement paved the way for the present-day group drive system.

Two Types of Motor-Drive Systems

Today, two general systems are in use for transmitting power from the prime mover, mostly the electric motor, to the various machines in the plant, namely:

1. **Individual drive system,** in which each machine is driven by its own motor (see Figure 146).
2. **Group drive system,** wherein two or more machines are driven by a common motor, through the medium of a lineshaft (see Figure 147).

Characteristics of Power Drives

These two systems each have their own set of advantages, disadvantages, and applications, as outlined in Table 13. Although either system can be used in many cases, the selection of the more suitable and economical one necessitates a careful analysis and proper comparison of the following characteristics of the two types of power drives:

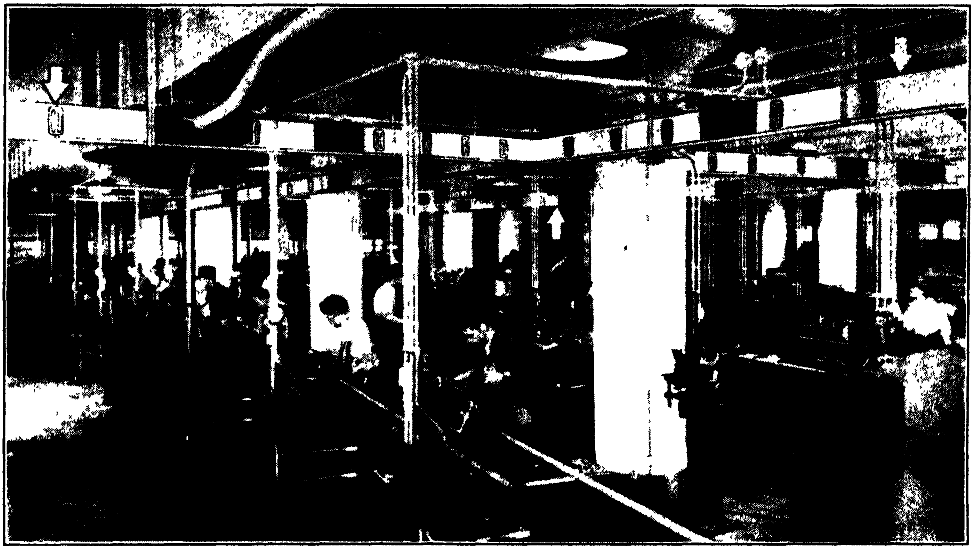


FIG. 146. *Individual drive system.* With the "plug-in" distribution system, considerable flexibility is provided for changing machine locations in the plant layout. (*Courtesy of Bull-Dog Electric Products Company, Detroit.*)

1. Plant layout flexibility
2. Speed variation
3. Speed control
4. Motor failure
5. Machine operations
6. Overhead shafting
7. Overhead space utilization
8. Hazards
9. First cost for installation
10. Annual cost of operation
11. Motor trouble consequences
12. Power factor
13. Power reserve

Seldom, except in very small establishments, are all the machines in the plant driven under one system. In most plants, the individual drive is usually advantageous for some machines, and the group drive for the other machines. A third possibility is the multi-automatic machines on which two or more motors are needed to operate the several features on a given machine. This compound-drive method is used principally to avoid complications in the design of the machine, particularly in gearing and shafting, to provide the necessary range of speeds and variety of operations.

TABLE 13. CHARACTERISTICS OF POWER DRIVES

For Transmitting Power from Prime Mover to Driven Machine

INDIVIDUAL DRIVE	GROUP DRIVE
Each machine is driven by its own motor. This is the favored type of power drive in modernized plants.	Two or more machines are driven by a common motor, through the medium of a lineshaft.
A. ADVANTAGES	
1. **Plant layout.** Provides greater flexibility for making changes in plant layout. 2. **Speed variation** in wider ranges. 3. **Speed control** obtained more easily. 4. **Motor failure** does not shut down more than one machine at a time. 5. **Machine operations** are more flexible because of having to operate only the machines that are needed. 6. **Overhead shafting** cost and maintenance are non-existent. 7. **Overhead space** above machines is clear and available for cranes, conveyors, etc. 8. **Hazards** of broken belts and of dirt from overhead pulleys are eliminated. 9. **Appearance** is neat and compact. 10. **Maintenance** is less complicated.	1. **First cost** for installation is usually cheaper. 2. **Annual cost** of fixed charges and maintenance is cheaper.
B. DISADVANTAGES	
1. **First cost** for installation may be up to 200 percent greater than for a corresponding group drive. 2. **Annual cost** of fixed charges and maintenance may run from 25 to 60 percent higher.	1. **Plant layout.** Less flexibility for making changes in floor layout. 2. **Speed variation** in more limited ranges. 3. **Speed control** is more difficult. 4. **Motor failure** causes a group shutdown. 5. **Machine operations.** Necessary to operate more machines than needed when only a few machines of the group are needed, unless a clutch is used. 6. **Overhead shafting** entails additional cost, maintenance, and accident hazard. 7. **Overhead space** occupied by lineshaft curtails the effective operation of cranes, conveyors, and other overhead equipment. 8. **Hazards** of broken belts and of dirt from overhead pulleys are introduced. 9. **Appearance** is less pleasing.
C. APPLICATIONS	
1. **Plant layout.** On machines that *a*. Are subject to frequent changes in location, *b*. Are scattered over a large area, or *c*. Are located at various angles. 2. **Overhead shafting.** On machines that would require countershafts if operated in a group. 3. **Overhead space.** In areas requiring service from overhead cranes or conveyors. 4. **Power load.** On machines imposing a fairly constant load.	1. **Power variation.** When power required on the machines varies considerably. The use of a flywheel with individual drive, however, may compensate for this variation. 2. **Machine operations.** On machines that are in fairly constant operation. 3. **Power load.** On machines occasionally requiring extreme peak loads for a few seconds at a time. Again, the use of a flywheel with individual drive may fulfill this requirement.

Layout of Power-Motor Drives

Individually driven machines may be located and moved around in a plant layout without much difficulty. The layout of group-driven machines, however, is largely dependent upon the problem of locating the lineshaft. The accepted practice in laying out and mounting the individual drive is compared in Table 14 with the corresponding factors inherent in the group drive.

TABLE 14. LAYOUT AND MOUNTING OF POWER MOTOR DRIVES

INDIVIDUAL DRIVE	GROUP DRIVE
A. LAYOUT	
1. **Transmission of power** from motor: *a.* By direct connection of power motor to driven machine, *b.* Through speed-reduction unit built into the motor, or *c.* Through a separate speed-reducer between the motor and the machine. This reducer may be: (1) A variable-speed device, (2) A belt, (3) A chain, or (4) A gear.	1. **Transmission of power from motor:** **First stage:** by belt or chain from motor to lineshaft. **Second stage:** by belt from lineshaft: *a.* Direct to driven machine, or *b.* Through a speed-reducer between the lineshaft and the machine. This reducer may be: (1) A countershaft, (2) A variable-speed device, or (3) A train of gears on the machine.
2. **Power capacity of drive.** Ample allowance for high stresses; *a.* During starting of motor. Starting torque of motor is frequently five times the full-load torque. *b.* Under peak loads.	2. **Size of drive group.** Number of machines to a group depends on: *a.* Power required by each machine, and *b.* Length of lineshaft needed. When drive group is large, motor failure shuts down a greater number of machines. When drive group is small, motor losses and investment may be greater than for individual drives.
B. MOUNTING	
1. **Motors.** Should be mounted a few feet above the floor or on top of the driven machine, to avoid winding failures arising from entrance of foreign matter, such as water, oil, chips, etc., into open motors. Where large amounts of fumes, dust, lint, etc. are present in the air, it is often advisable to use fully inclosed, fan-cooled motors.	1. **Motors.** See notation at left for mounting motors on individual drives. For larger-size motors used on group drives, it is important to leave enough clearance under the motors to facilitate inspection, oiling, and replacement.
	2. **Lineshafts.** May be located overhead or under the floor level: *a.* **Overhead mounting.** On supporting structure such as roof supports or balconies. In either case, the structure must be strong and rigid enough to bear the weight of the lineshaft and to withstand the stresses developed in operation. *b.* **Subfloor mounting.** Motors and lineshafts installed in trenches or tunnels built into the floor beneath the rows of machines, and covered with steel floor plates.

Because of the stress requirements for lineshaft supports, it is frequently desirable to locate group-driven machines under balconies. The need for strengthening the balcony structure, however, must be as accurately ascertained as for strengthening the roof structure when the latter is used as the support for the lineshaft. If the roof structure is at a considerable height from the floor, it may be necessary to mount lineshaft hangers on columns or sidewalls.

The disadvantages of lineshafts may largely be eliminated by installing both the shaft and the drive motor in a trench or tunnel built into the floor, as illustrated in Figure 147. This particular trench is 24 inches deep and 20 inches wide. It is cast in the concrete floor directly beneath the rows of machines, and covered with steel floor plates. Belts protected by sheet-metal guards run upward to the machines through the plates.

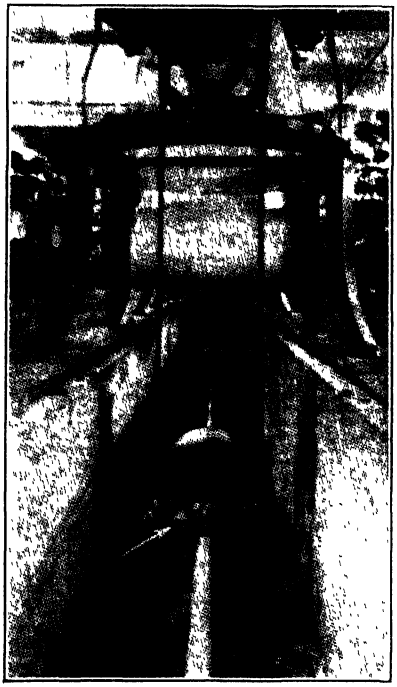


FIG. 147. *Group drive* mounted below floor level in a trench underneath the driven machines. Removable steel plates fit over the trench. (*Courtesy of* Factory Management and Maintenance.)

4. PLANT LIGHTING REQUIREMENTS, SOURCES, AND CIRCUITS

Main Objectives of Good Lighting

The two main objectives of good lighting in an industrial plant are:

1. **Accuracy of seeing** the critical details in each manufacturing operation
2. **Ease of seeing** these details by the brightness-contrast with their surroundings.

To achieve these objectives, it is frequently necessary to make changes in some or all of the following contributory factors:

1. Manufacturing method.
2. Surroundings and layout.
3. Lighting systems in the plant.

Benefits of Good Lighting

Attempts made to evaluate in tangible form the benefits of good lighting in a plant inevitably end up in rough estimates of actual conditions. This is due principally to the composite influence of the following general factors which do not readily lend themselves to correct measurement:

1. **Vision.** Improvement in accuracy, ease, and speed of vision at work stations.
2. **Morale.** Improvement in morale and reduction in labor turnover.
3. **Housekeeping.** Improvement in order and cleanliness and in appearance of the plant.

4. **Production.** Increase in production, quality, and supervision, with attendant decrease in rejects.
5. **Accidents.** Reduction in eyestrain and fatigue accompanied by a measurable decrease in accidents.

Lighting Requirements for a Plant Layout

In attempting to establish lighting requirements in a plant, specific problems requiring special study fall into the realm of illumination engineering rather than of plant layout engineering. For general investigation work, however, the following three measuring devices are available to the plant layout engineer:

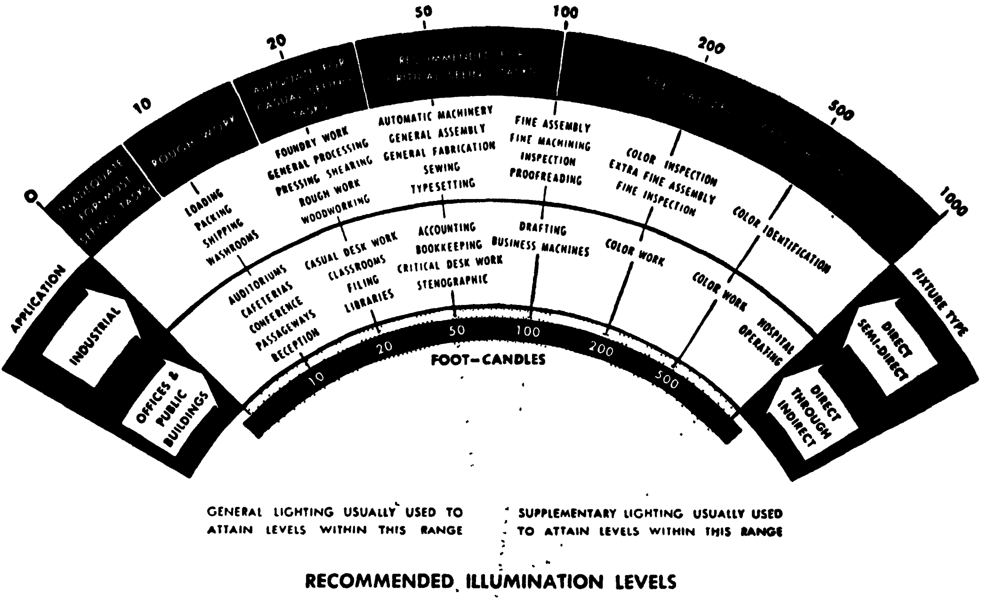


FIG. 148. (*Courtesy of* Factory Management and Maintenance.)

1. **The foot-candle meter.** Foot-candle readings taken at all work stations, storerooms, offices, and service areas are jotted down on the plant layout or are compiled in tables.
2. **Tables of recommended illumination levels.** A graphic summarization of such tables is shown in Figure 148 for different classes of work. By comparing the foot-candle meter readings with the intensities recommended in the experience table for the corresponding classes of work, the adequacy of the existing lighting system can be readily ascertained. For new plant layouts, the experience tables provide a ready guide.
3. **The visibility meter.** This device enables the plant layout engineer to determine closely the minimum amount of light required for operations where it is desirable to secure more accurate measurements than through

the use of the foot-candle meter readings in conjunction with experience tables on intensities of lighting.

Tables giving the levels of illumination recommended for a number of operations in various types of industries are published in the *American Recommended Practice of Industrial Lighting* prepared under the sponsorship of the Illuminating Engineering Society. The values given in these tables are briefly summarized in Figure 148.

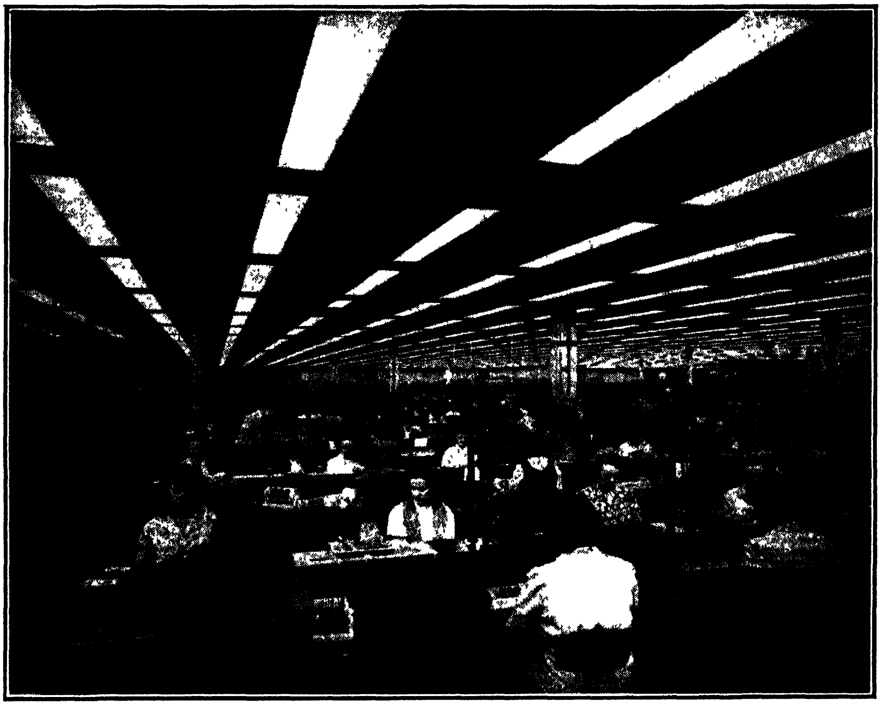


FIG. 149. *General lighting* in the assembly department of a naval ordnance plant. Note the controlled conditions of high-level illumination, air-conditioning, and acoustical ceiling to provide comfort for employees and assure quality of product. (*Courtesy of the Austin Company, Cleveland.*)

General and Localized Lighting

The lighting of a plant is generally supplied under the following two classifications or systems, each possessing its own characteristics and functions:

1. **General lighting.** The generally uniform level of illumination provided throughout the work area through the medium of continuous rows or other arrangement of lighting units spaced symmetrically overhead (see Figure 149).
2. **Localized lighting.** In areas where the general lighting does not provide the needed higher levels of illumination at certain work stations, the lighting units are placed in direct relationship to the machines in the work stations.

Types of Industrial Lamps

The three types of lamps commonly used for industrial lighting are the following:

1. **Incandescent lamps.** It is important that these lamps are of correct wattage size to fit the lighting equipment and are also of correct voltage rating.
2. **Fluorescent lamps.** Although not introduced until the early 1940's, these lamps now constitute one of the most important sources for industrial plant lighting.
3. **Mercury-vapor lamps.** The type H lamp, or high-pressure lamp, has gained extensive acceptance in high-bay applications. Being deficient in the red rays, these lamps are usually installed where color discrimination is not an important factor.

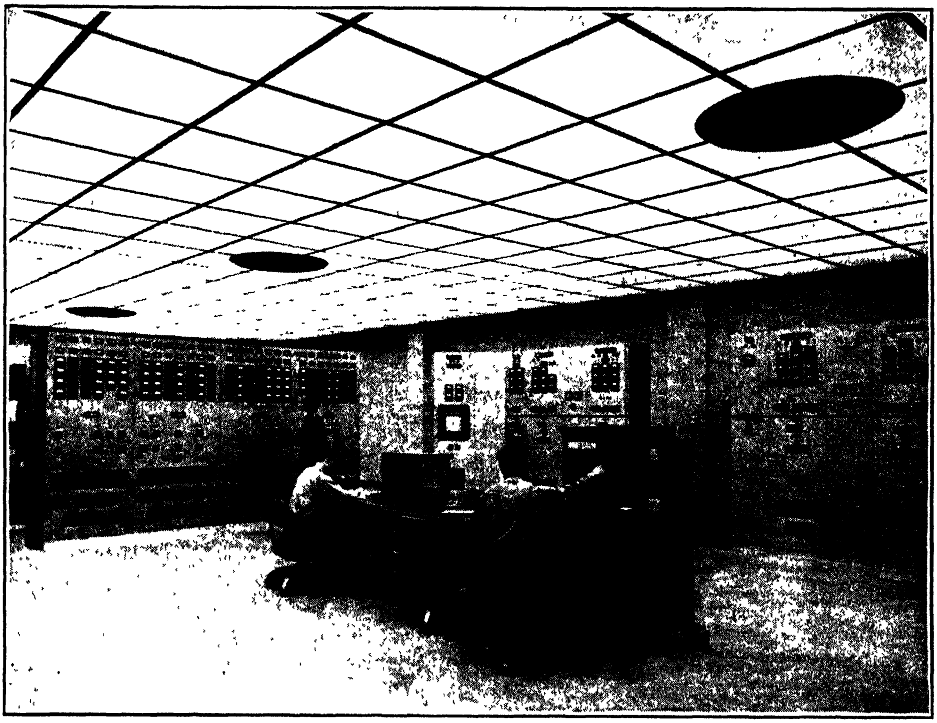


FIG. 150. *High-intensity cold-cathode lighting* installed in control room of the Barbadoes Generating Plant of the Philadelphia Electric Company.

A new type of lighting developed in the late 1940's is the high-intensity cold-cathode system illustrated in Figure 150. The lighting units are entirely hidden above the translucent, glass-paneled ceiling through which a soft bluish-white light is distributed evenly over the entire area under the ceiling. According to observations in actual installations, the total cost of this lighting compares favorably with that of the fluorescent-lamp system.

CHAPTER XVIII

Planning Office Layouts

The Need for Office Planning

It has been the custom in many plants to allocate space for offices without previous study of actual requirements. This applies both to occupancy and location. When this occurs, the result is an awkward arrangement, a waste of space, or both.

The same degree of analysis can and should be applied to office planning as is usually done for the manufacturing facilities. The efficiency with which an office employee performs his task is considered just as important to the business as is the performance of the shop operator. To a large extent the selection and arrangement of equipment, as well as of working conditions, influence performance in both cases.

1. LOCATING THE OFFICES AND ALLOCATING FLOOR AREAS

In selecting the location for an office area, a first consideration is the geographic location with respect to the plant functions it is to serve If the department that the office is to house has most of its contacts with persons from outside the plant, then it should be readily accessible from the street. If most contacts are of an internal nature, then consideration should be given to locating it near the center of these contacts.

If the office is to share a building housing plant activities, such as warehousing, storage, shipping, etc., it is often desirable to place the office on an upper floor, when elevators are available. This leaves the lower floors for factory or warehouse purposes to facilitate the movement of material from receiving or to shipping platforms or to other shop departments at a minimum of transportation and handling cost. From the office standpoint, the top floor provides better light and less noise from the factory or warehouse activities carried on in the same building.

In plants where the offices are located in various buildings or where there is an appreciable amount of foot traffic between the office and the adjoining plant buildings, special attention must be given to the medium of access between these points. It is sometimes advisable to build connecting bridges, tunnels, or other forms of passageways for free circulation of foot traffic between buildings during inclement weather.

Common Oversights in Office Planning

Perhaps the most common mistake made in planning office space requirements is to underestimate the possibilities of future expansion. Short-sightedness in this respect has caused many plants to give up their office space and construct a new building in order to accommodate the expanded office force. With the increasing number of women employed in offices, it is necessary to include adequate facilities for women in the provision for future expansion.

Another common oversight in office planning is the failure to provide enough storage and vault space for records. The employees are frequently compelled to travel too far to the vaults. Oftentimes not only larger vaults but more of them are needed. This problem may, however, be somewhat alleviated by microfilming the records.

FIG. 151. *Modern general office.* Stenographic department in the Wm. Wrigley, Jr. Company's offices in Chicago. Ceiling is soundproofed and carries air-conditioning ducts. Two sides of the room have natural light and ventilation. Floor is covered with soundproofing linoleum and is free of electric conduits. Round-edged metal desks are equipped with posture chairs and reading stands. Note orderly aisle alignment. (*Courtesy of U.S. Gypsum Company.*)

Basic Information for an Office Layout

As in the case of laying out a shop department or a factory floor, a number of fundamental space requirements must be determined before the first attempt is made to lay out office space. The more important basic information commonly needed includes the following:

1. **Office functions.** Location, arrangement, and accommodations vary widely between different functional types of offices. Administrative and sales offices usually have to accommodate outside visitors upon whom the appearance of the office leaves an impression which influences their goodwill towards the company. Purchasing and personnel offices likewise receive

visitors continually, but the office appearance is not so crucial an issue in this case. General offices (Figure 151), drafting rooms (Figure 152), tabulating rooms (Figure 153), production control offices, etc., likewise each present different combinations of requirements as to light exposure, floor loading, distance from plant activities, communication facilities, and internal appointments. The flow of authority in the company's organization chart frequently exerts an insurmountable influence on the arrangement of offices in a layout.

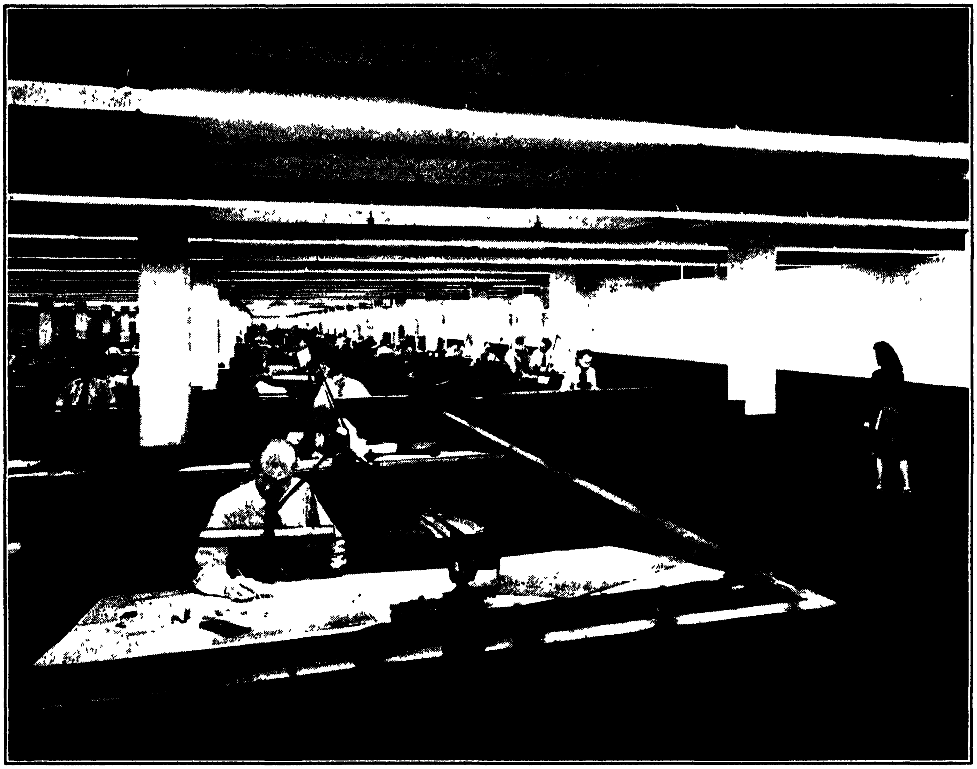


FIG. 152. *Drafting room without partitions* at Pratt & Whitney Aircraft Corporation's Kansas City plant. This arrangement provides a segregation of activities without the use of full-height partitions. The aisle is located along the outside wall to allow the maximum area layout without the intervention of a bisecting aisle. (*Courtesy of Albert Kahn Associated Architects and Engineers, Detroit.*)

2. **Conference rooms.** The size and frequency of the conferences to be held will determine the amount of floor space to be set aside for conference rooms. This provision is frequently squeezed in as an afterthought or made as a subterfuge to absorb unexpected excess space after the layout has been completed. Advance consideration given to this requirement will assure better locations and more adequate space for conference rooms, and less likelihood of discovering "white elephants" after the planning is done.

3. **Office force and equipment.** In order to allocate suitable areas to each department, the plant layout engineer must have a list of office personnel denoting executives and their secretaries, department heads and their key assistants, office-machine operators by types of machines operated, and general clerks by types of duties. For each person appearing on these departmental lists, it is necessary to show the quantity and type of office furniture, equipment, machinery, special filing, and storage and communication facilities required. With this information at hand, the plant layout engineer is ready to start roughing out an area location and allocation for each department.

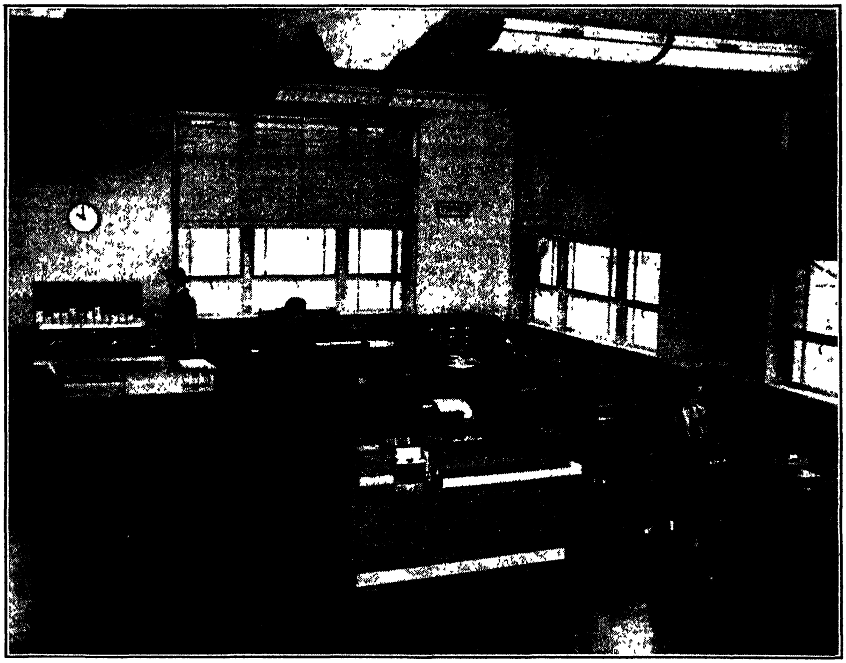


FIG. 153. *Punched card accounting-machine room.* Medium-sized installation of punched card equipment in office quarters. Note generous aisle space around each machine unit, and location of key punches so that operators have natural light over their left shoulders. Fluorescent lighting, acoustic ceiling, and linoleum flooring are particularly conducive to operator efficiency in this type of office. (*Courtesy of International Business Machines Corporation, New York.*)

Figure 154 specifically illustrates the importance of knowing in advance the functions, number of personnel, and description, type, and size of furniture, machinery, and equipment required in each particular department before planning a layout. The mail department in this photograph consists of many thousands of scientifically numbered subscriber bins into which millions of credit reports a year are collected and from which they are pulled daily for mailing. An office area of this kind requires bin sections of predetermined specifications; a network of aisles laid out to conserve floor space without giving rise to excessive walking; adequate lighting facilities; and instant access to all individual bin compartments. The planning requirements shown here on a large-scale operation apply in corresponding degree to a smaller office department, such as a lonely addressograph room, if the layout is to be an efficient one upon completion.

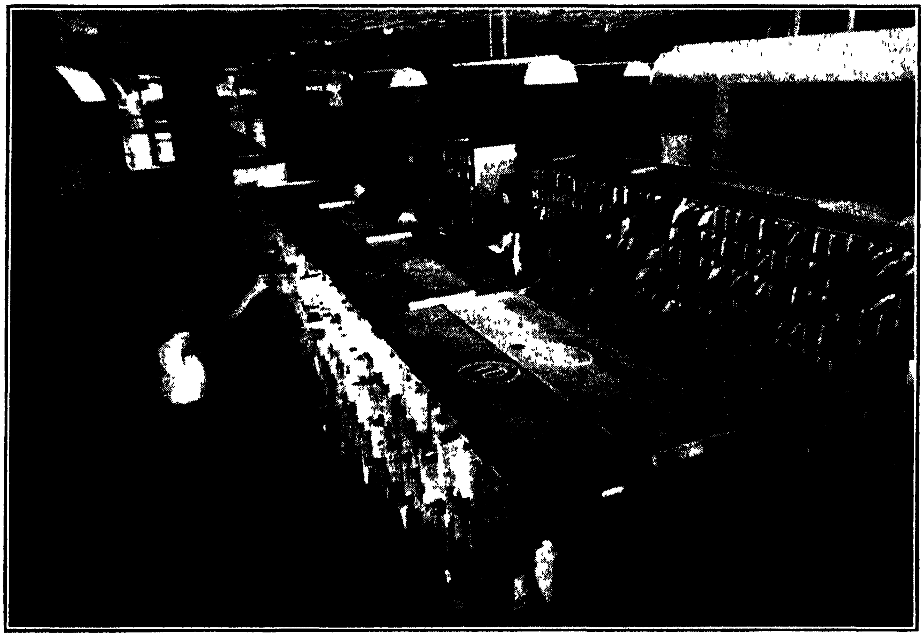


FIG. 154. *A mail department in high gear* for routing millions of credit reports a year in the New York offices of Dun & Bradstreet, Inc. The department is laid out in bin sections identifiable in the photograph by circled numbers on the top surface of each section. Each bin section is so designed that a mail clerk can reach all the bin boxes within the section from one standing spot. Each bin box is subnumbered to denote a particular subscriber to the report service. Each box contains a supply of envelopes prestenciled with the subscriber's number, name, and address. When the supply in any box runs down to three envelopes, the stencil is removed from inside the box and sent to an electric stenciling machine for replenishment. Mail matter is presorted by bin sections before the mail clerks take it to a section for stuffing into bin boxes. At the end of the day, the mail in each box is stuffed into a prestenciled envelope and released to a sealing and postage-metering machine. (*Courtesy of Dun & Bradstreet, Inc.*)

2. TYPES OF PRIVATE AND GENERAL OFFICES IN A PLANT

Size and Boundary of Office Areas

After segregating the functions, personnel, furniture, machinery, and equipment of each office department into a separate floor area on the area-allocation diagram, the next step is to determine the size and boundaries of each departmental area. In a manufacturing plant, office-departmental areas may consist of the following:

1. **Administrative offices.** This area usually includes separate private offices for the board of directors, president (Figure 155), each vice-president, the treasurer, secretary, conference room, reception room or lobby, and a room for the private secretaries.
2. **Executive offices.** Separate private offices for sales manager, advertising manager, production manager, traffic manager, purchasing agent, comptroller, personnel manager, engineering manager, director of research, and adjoining open areas for the staff assistants and stenographers. In many establishments, the administrative and executive offices are intermingled, depending upon the size and type of company organization.
3. **General offices.** These are usually large areas housing from half a dozen or so clerks in small plants, to a large group comprising hundreds of clerks in the larger establishments. There may be a general office for each of such departments as payroll, general accounting, cost accounting, credit, sales order and billing, purchasing, engineering, production planning, marketing, sales research, advertising, tabulating machines, typing, duplicating, etc. Within these general offices, the smaller companies frequently set up small private offices for department heads, buyers, sales correspondents, and influential staff assistants.

FIG. 155. *President's office* at the plant of the Louisville, Ky., *Courier-Journal* and *Louisville Times*. See Figure 185. (*Courtesy of Lockwood Greene Engineers, Inc., New York.*)

4. **Shop offices.** In this group are various areas, either with or without partitions, assigned to such functions as plant superintending, plant engineering, production scheduling, stock ledgers, employment, medical, product research, timekeeping, foremanship, and shipping.

Private versus General Offices

The extent to which private offices are justifiable for single occupancy, or for small groups up to about a dozen people, has long been a debatable point. The advantages claimed for the private office on the one hand, and for the general office on the other, may be summarized as follows:

ADVANTAGES CLAIMED FOR SMALL OR PRIVATE OFFICES

1. Segregation of employees increases efficiency by reducing distraction and temptation for "horseplay."
2. Less disturbance from noise of office machinery.
3. Better utilization of floor space by being able to place furniture and equipment against partitions.
4. Heating, lighting, ventilation, and painting can be adapted more directly to suit particular activities.

ADVANTAGES CLAIMED FOR GENERAL OFFICES

1. Less floor space required per employee.
2. Better supervision through closer contact between the department head and the employees.
3. Less confusion through better access to files and other groups integral to a department.
4. Less office machinery through wider common use made of the machinery.
5. Less investment in the layout.
6. More flexibility and quicker installation of the arrangement.

In every case of office planning, the determination of over-all space requirements should be made without thought of segregation. After the general space requirements are known, the number of private offices required can be ascertained on a sound basis.

3. STANDARD SPECIFICATIONS FOR LAYING OUT OFFICES

Average Clearances and Dimensions

Average minimum clearances and generally accepted standard specifications serve as guides to plant layout engineers in the development of plans suited to the particular conditions of the layout. This section contains information on doors, windows, corridors, and average minimum clearances necessary around typical units of office furniture. Data are based on standard sizes of office furniture and equipment, plus allowance for the space taken up by the person occupying the unit. Variations in dimensions, whenever they appear, are principally due to variations in furniture sizes. Space and room limitations indicated are not to be considered absolute, but only typical. In every case more liberal allowances should be made where it is possible to do so.

Doors. A door should swing inside the private office, as illustrated in Figure 156. It should be so located that it will swing back against the cross-partition to give the greatest flexibility for furniture layout. This arrangement also provides the maximum wall space. Pair doors are used to give a wider opening, but generally this is unnecessary. Double-acting doors require swinging space on both sides of the partition, and entail the danger of striking a bystander. Interior doors are usually 7 feet high. The door plus transom reaches a height of 8 feet, 6 inches.

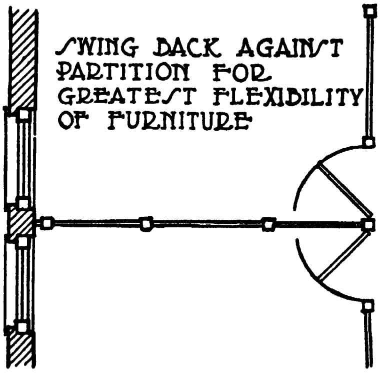

SWING BACK AGAINST PARTITION FOR GREATEST FLEXIBILITY OF FURNITURE

FIG. 156. *Doors.* Location and swing. (*Courtesy of E. F. Hauserman Company, Cleveland.*)

Ceiling heights. A minimum clear height of 9 feet, from floor to ceiling, is recommended in office areas.

Angular partitions. A layout involving angular partitions should be avoided as it is wrong in appearance, wasteful of floor space, and awkward for furniture arrangement. An economical method of designing corridor access to corner offices involving partition angles is illustrated in Figure 157.

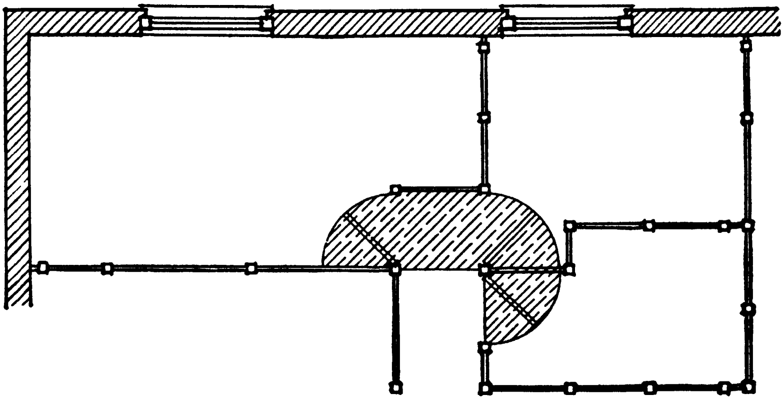


FIG. 157. *Partition angles* with economical corridor access to corner offices. (*Courtesy of E. F. Hauserman Company, Cleveland.*)

Window-sill heights. These are relatively standardized at approximately 2 feet, 6 inches, although some are as high as 3 feet. The sketches in Figure 158 illustrate methods of determining sill heights in special cases where furniture and equipment are the governing factors.

Corridors. Corridors vary in width, but average 6 feet in most large offices. The minimum corridor width is set by some codes, in which case it must equal the minimum exit-door width. Methods for determining corridor widths in accordance with human figure dimensions are shown in the drawings in Figure 159. With a minimum radius of 4 to 5 feet at all corridor intersections and with stairs wide enough to handle two-way traffic and moving of equipment, many difficulties can be avoided. The recommendations of the National Safety Council and American Standards Association may be helpful guides.

Desk clearances. Average minimum clearances around standard desks of different types are illustrated in Figure 160. Ranges in the dimensions shown are

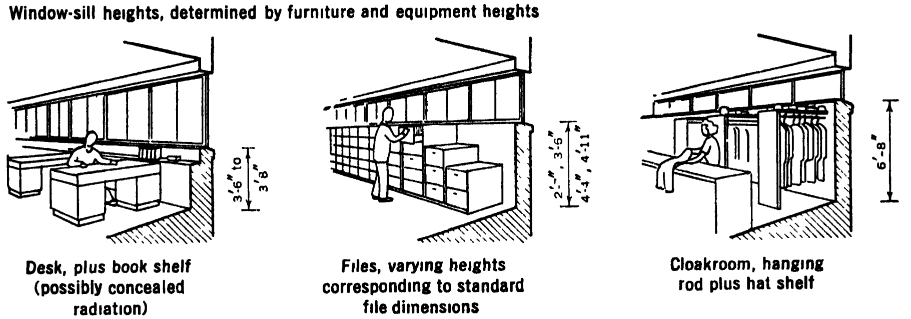

Window-sill heights, determined by furniture and equipment heights
3'-6" to 3'8"
2'-", 3'-5"
4'-4", 4'-11"
6'-8"
Desk, plus book shelf (possibly concealed radiation)
Files, varying heights corresponding to standard file dimensions
Cloakroom, hanging rod plus hat shelf

FIG. 158. *Window-sill heights.* Determined by heights of furniture and equipment. (*Courtesy of* Architectural Record.)

principally due to variations in desk sizes. Allowances for passage, bookcases, and files are also shown for various arrangements. Space for wastebaskets is likewise illustrated.

Filing cabinets. Standard clearances for both legal- and letter-size filing cabinets are shown in Figure 161. In laying out files, careful consideration must be

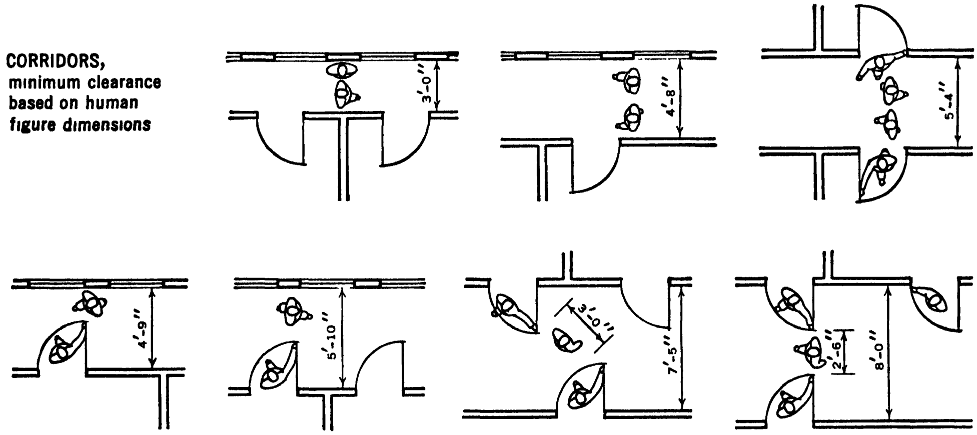
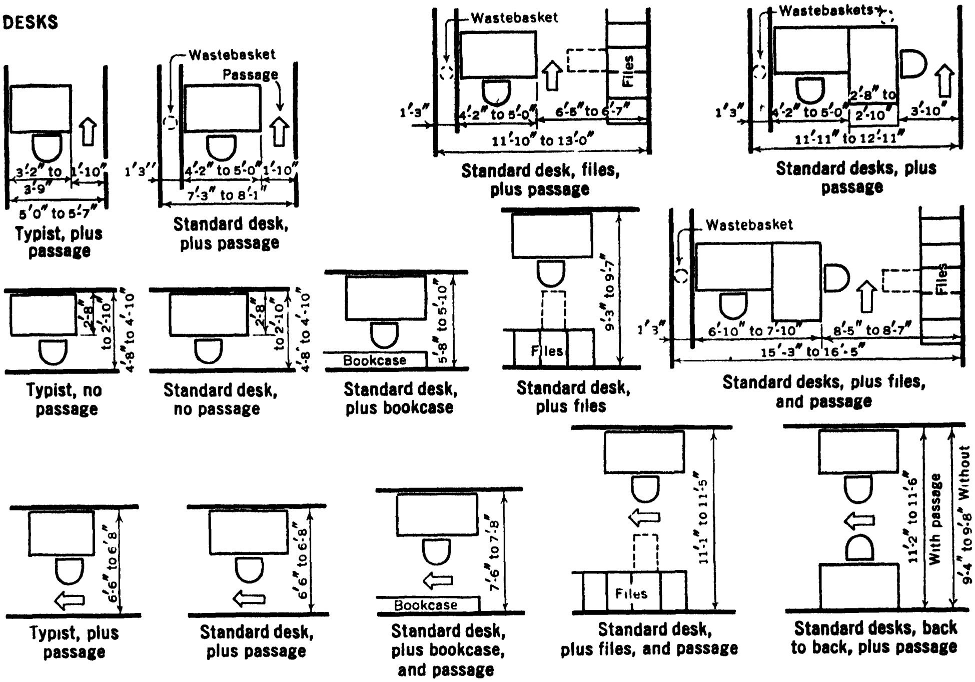

CORRIDORS, minimum clearance based on human figure dimensions
3'-0"
4'-8"
5'-4"
4'-9"
5'-10"
3'-0"
7'-5"
2'-6"
8'-0"

FIG. 159. *Corridors.* Minimum clearance, based on dimensions of human figure. (*Courtesy of* Architectural Record.)

given to open drawers and passage space when files face an obstruction, such as a partition or desk, and when they are placed face to face. In selecting filing cabinets, the height of the cabinets may pose a critical problem.

Shelving. In Figure 162 are shown the standard clearances for access to shelving, and for both access and passage when the shelving faces an obstruction such as a railing or desk.



Typist, plus passage

Standard desk, plus passage

Standard desk, files, plus passage

Standard desks, plus passage

Typist, no passage

Standard desk, no passage

Standard desk, plus bookcase

Standard desk, plus files

Standard desks, plus files, and passage

Typist, plus passage

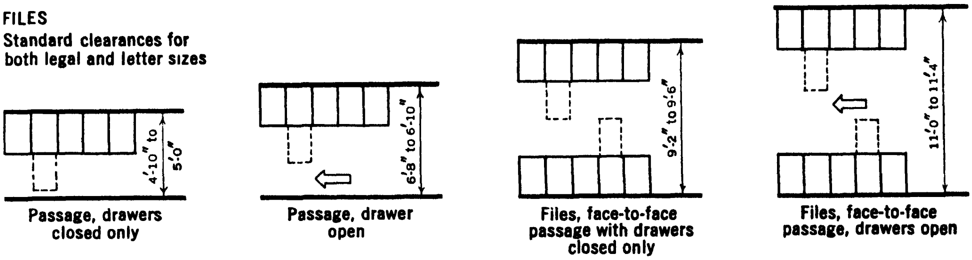
Standard desk, plus passage

Standard desk, plus bookcase, and passage

Standard desk, plus files, and passage

Standard desks, back to back, plus passage

FIG. 160 *Desks and occupants* Average minimum clearances around typical units. (*Courtesy of* Architectural Record.)



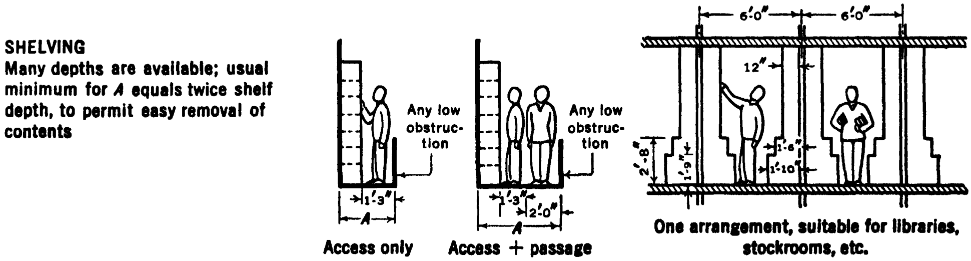
Passage, drawers closed only

Passage, drawer open

Files, face-to-face passage with drawers closed only

Files, face-to-face passage, drawers open

FIG. 161. *Filing cabinets.* Standard clearances for both legal and letter sizes. (*Courtesy of* Architectural Record.)


SHELVING
Many depths are available; usual minimum for A equals twice shelf depth, to permit easy removal of contents
Any low obstruction
1'3"
A
Any low obstruction
1'-3"
2'-0"
A
6'-0"
6'-0"
12"
2'-8"
1'-9"
1'-6"
1'-10"

Access only

Access + passage

One arrangement, suitable for libraries, stockrooms, etc.

FIG. 162. *Shelving.* Standard clearances for access, and access and passage. (*Courtesy of* Architectural Record.)

Off-center partitions. The column centers of multi-story reinforced concrete office buildings are generally between 15 feet and 25 feet. There are often two windows between columns. The square area inclosed within four columns, one column at each corner, is called a bay. It is often assumed that column centers arbitrarily determine office widths, particularly for private offices. This rule is not necessarily binding. Figure 163 shows an office where the partitions do not follow column center lines. The result is flexibility in the widths of offices.

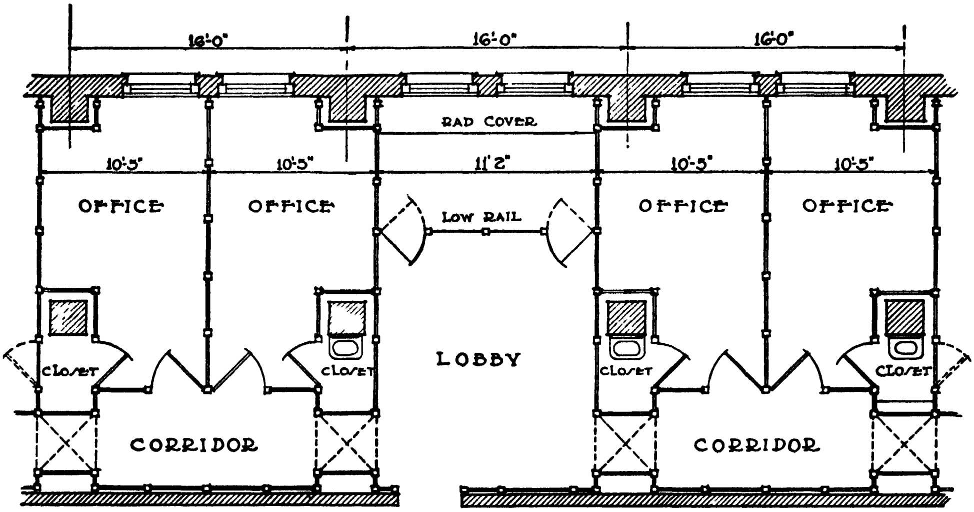


FIG. 163. *Off-center partitions.* Symmetrical layout independent of column- or window-spacing. (*Courtesy of E. F. Hauserman Company, Cleveland.*)

4. BASIC PLANS FOR LAYING OUT GROUPS OF OFFICES

Planning private offices. The width and length of a private office are often selected to accord with the desk arrangement which the occupant desires. Figure 164 illustrates seven typical arrangements for private offices, together with average minimum clearances which govern the width and length of the office in each case. The planning of private offices for executives is made more in accordance with personal preferences than with the minimum dimensions illustrated here. For private offices other than for executives, however, the illustrated dimensions provide a guide for office planning and layout.

Foundation plans for small offices. A logical plan for laying out a group of small offices within an area of two bays is illustrated in Figure 165, with a centralized lobby as a focal point. A second arrangement for the same space is shown in Figure 166, with a single general office provided with a separate entrance. These two layouts may be considered as foundation plans for small offices. Other layouts for this size of space are merely variants worked out by rearranging one of these two plans to suit the conditions at hand.

Three-dimensional office layouts. An office may be laid out in three-dimensional form through the use of miniature models of office furniture, equipment, machinery, personnel, and partitions as illustrated in Figure 167. This represents the existing layout at the Brock-Hall Dairy Company, New Haven, Conn., at the time a new layout was being designed. The models are positioned on cross-section paper, of four divisions to the inch. In planning a new layout, these models are shuffled around and placed in position to provide a preview of various arrangements of the offices, aisles, doors, and corridors without spending long hours in preparing detail layout drawings.

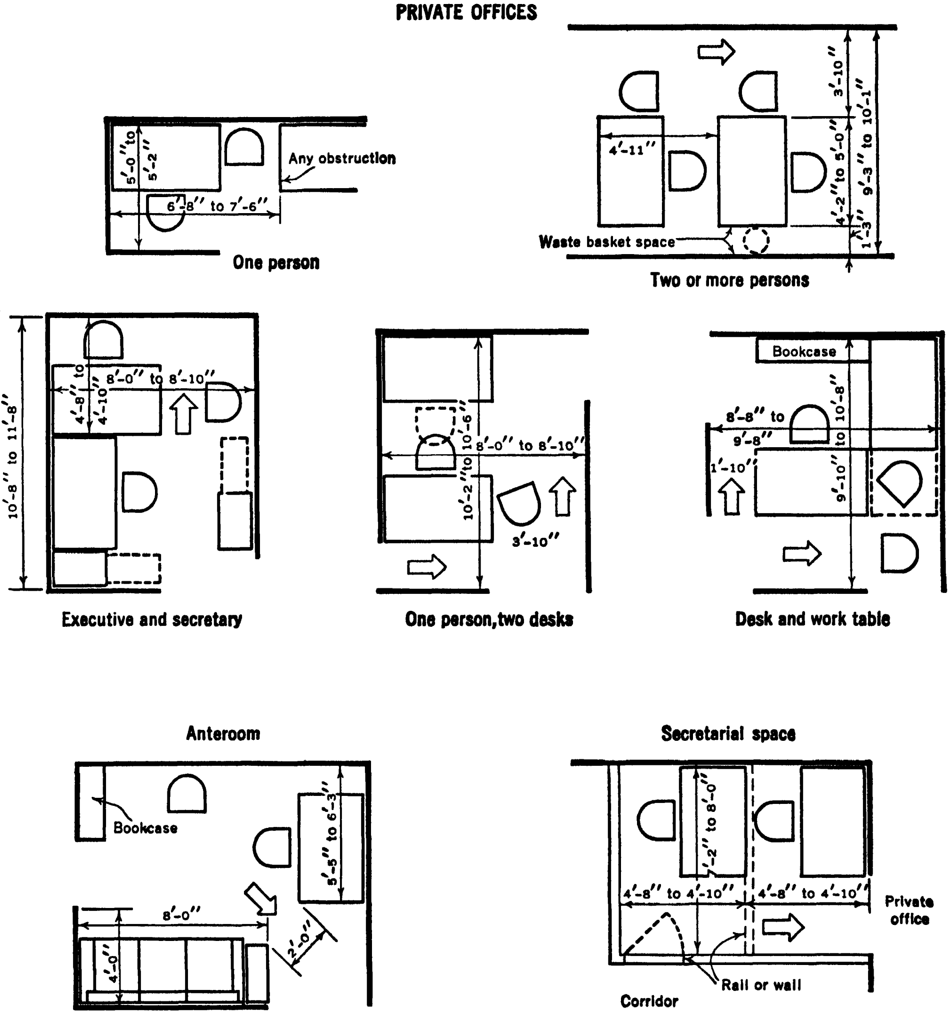
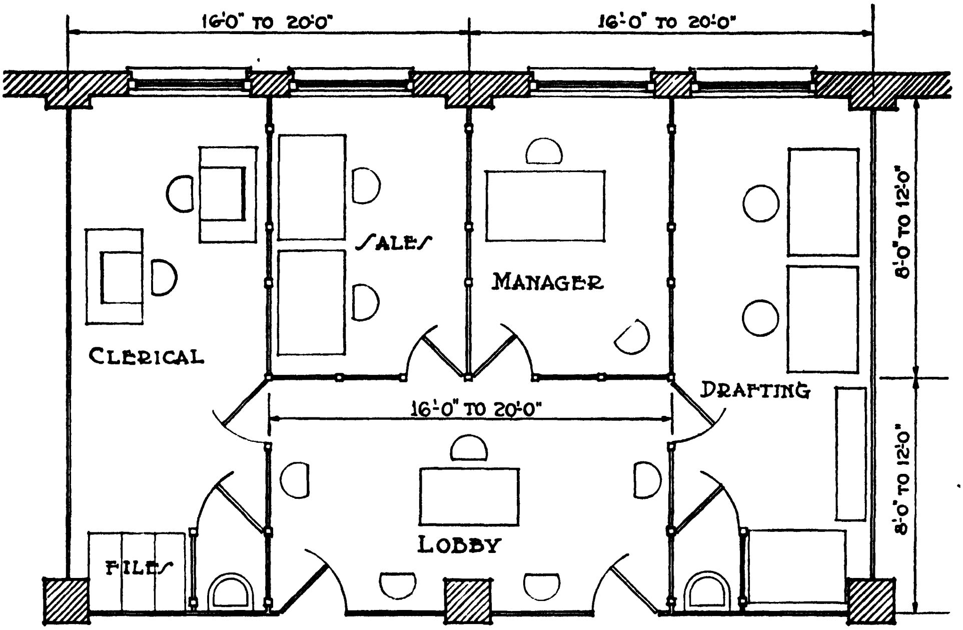
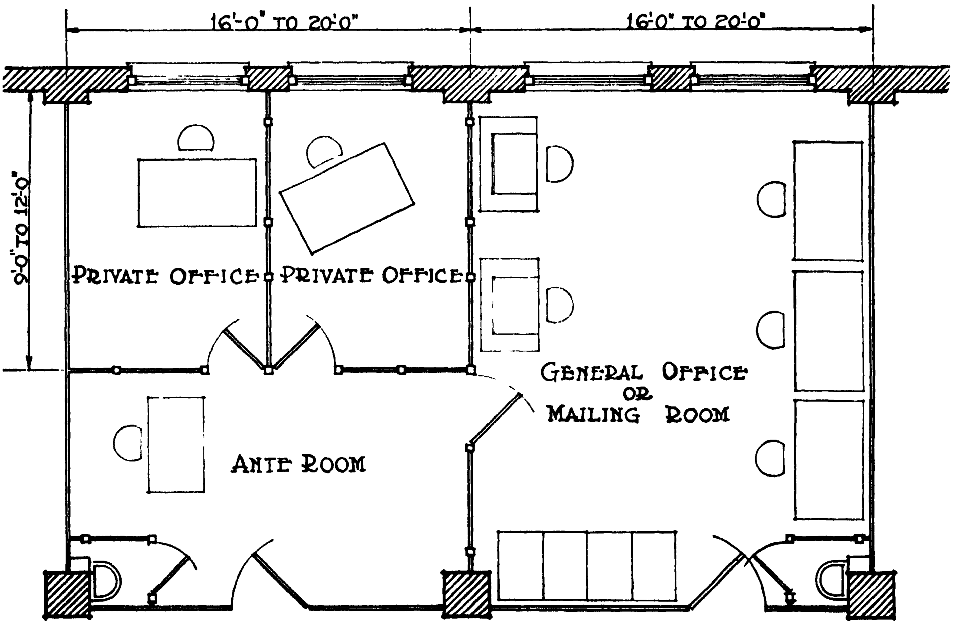


FIG. 164. *Private offices.* For single desk, desk and table, two desks, and over two desks. (*Courtesy of* Architectural Record.)



FOCAL LOBBY

FIG. 165. *Centralized lobby* for small offices. A logical plan for laying out a group of small offices with a centralized lobby as a focal point. (*Courtesy of E. F. Hauserman Company, Cleveland.*)



GENERAL OFFICE

FIG. 166. *Second arrangement for space* shown in Figure 165, with a single general office provided with a separate entrance. (*Courtesy of E. F. Hauserman Company, Cleveland.*)

5. OFFICE LIGHT, HEAT, VENTILATION, AND ACOUSTICS

Facilities for office efficiency. When the office layout has been developed to the point where private offices and departmental areas have been allocated and enclosed on the plan by the corridors, partitions, and aisles, the next step is to spot each piece of office furniture, equipment, and machinery on the layout. This is followed by making suitable provision for furnishings, illumination, temperature control, and acoustical treatment.

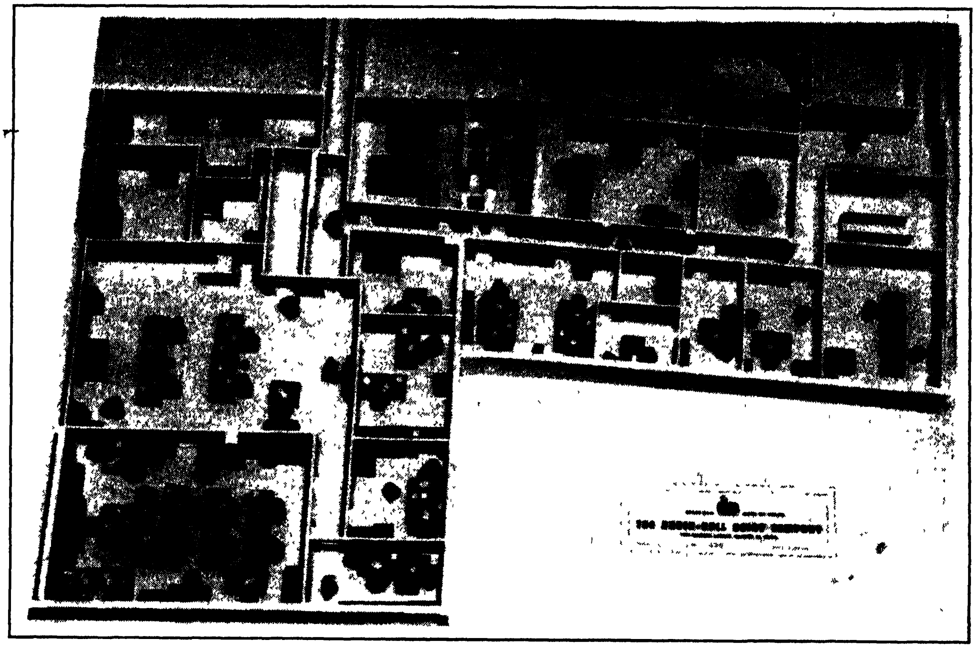
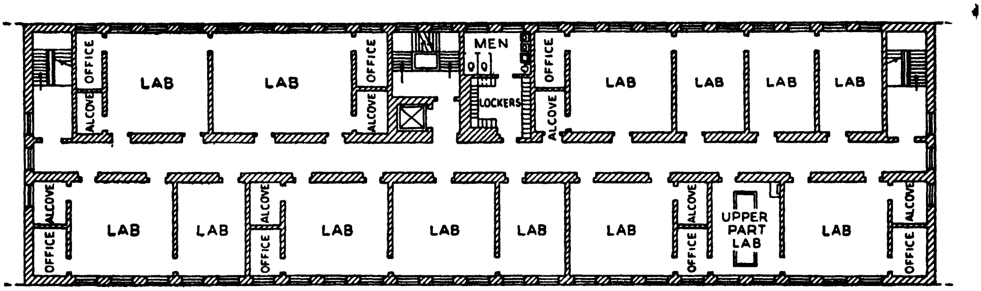


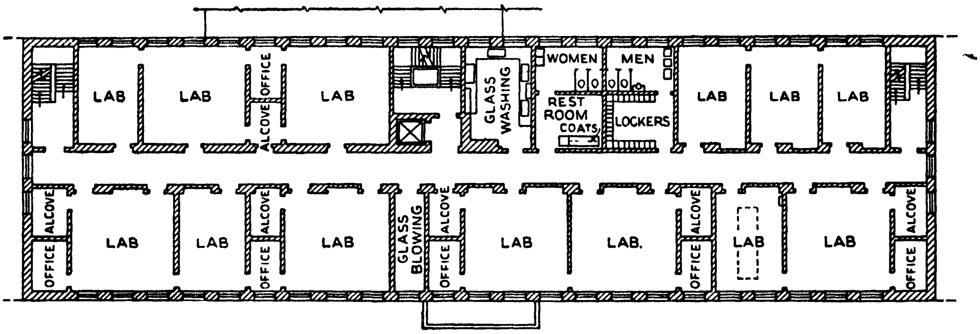
FIG. 167. *Use of miniature models* in the layout of the offices of the Brock-Hall Dairy Company, New Haven, Conn. *(Courtesy of Stevenson, Jordan & Harrison, Inc., New York.)*

Because of the normally greater nervous tension and mental strain integral to office work than to shop activities, the factors of light, heat, ventilation, and acoustics are usually more significant to office workers than to the plant force. The result of planning properly for these requirements is a group of well-lighted, air-conditioned, acoustically treated private offices, general offices, and conference rooms which provide adequate facilities for efficiency in office work. By providing the most modern facilities for its employees, the higher productivity obtained from a contented personnel offers a pointed challenge to a management that may question the amount of tangible return on investment in such improvements. A layout incorporating these principles in a three-story administration and chemistry building is illustrated in Figure 168.

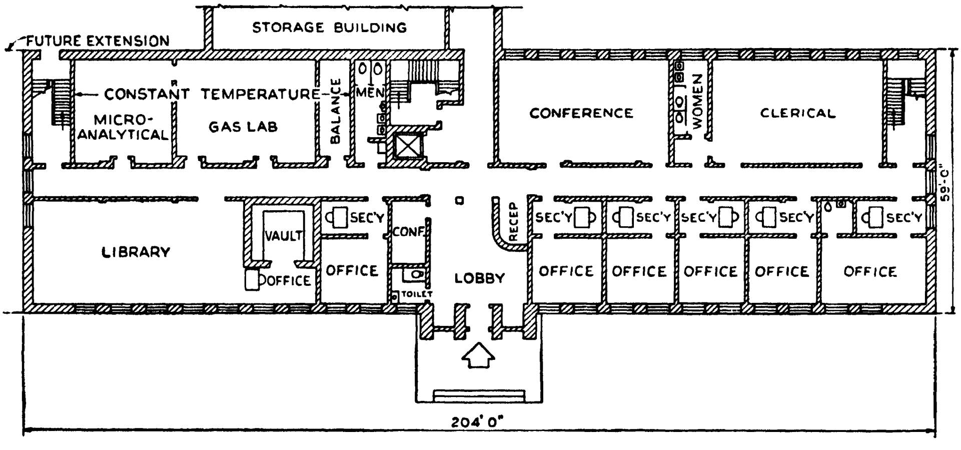
Appearance of offices. When desks are well-spaced, the tops of filing cabinets are at a uniform level, and aisles are carefully laid out, an atmosphere of effi-



THIRD FLOOR



SECOND FLOOR



FIRST FLOOR

FIG. 168. *Study plans* of administration and chemistry building, research and development laboratories of the Pure Oil Company, Crystal Lake, Ill. An intermediate stage in preparation of plans for initial portion of main building on a major research and development project in the petroleum field. (*Courtesy of Stone & Webster Engineering Corporation, Boston.*)

ciency prevails in the office appearance. A homelike touch is often added by a scattering of potted plants at strategic spots. The same pleasing pattern extends into the private offices. It is greatly enhanced in executive offices by Venetian blinds, heavy carpets, upholstered chairs, built-in bookcases and equipment, oil paintings, fireplaces, etc. A modest attempt to equip a private office with some of these furnishings is shown in Figure 169. In general offices, a floor covering of marbelized linoleum or of rubber tile not only considerably improves the appearance of the office but also helps materially in deadening the noise of office machinery and the clatter of moving chairs and footsteps.

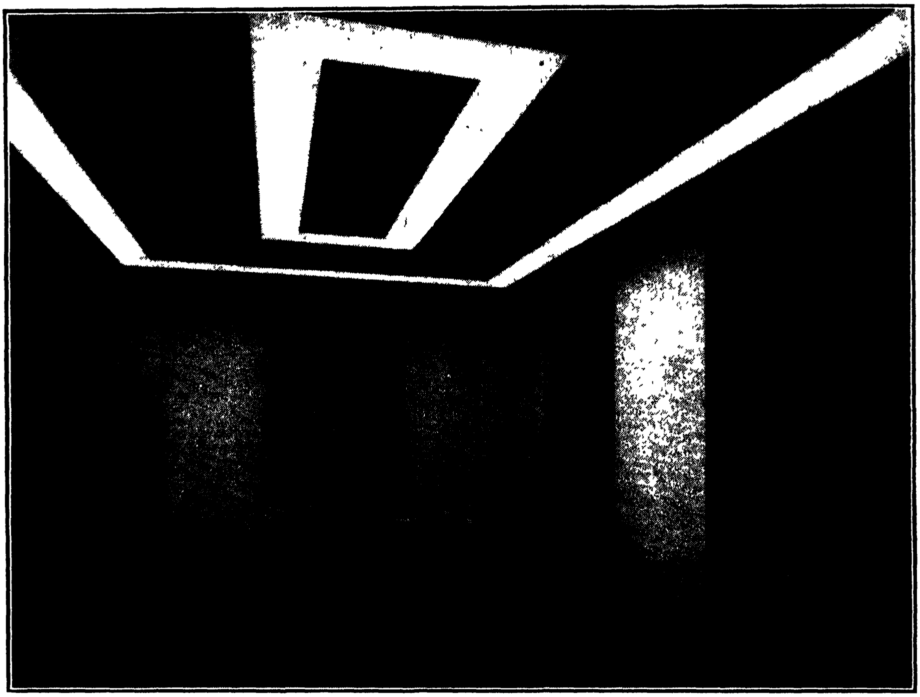


FIG. 169. *Office appointments.* Venetian blinds, carpeting, upholstered chairs, and bookcase provide an air of success and comfort in this unpretentious private office. Note the striking pattern of the recessed lighting with concealed tubes producing symmetric bands of illumination which are flush with the acoustically treated ceiling. (*Courtesy of U.S. Gypsum Company.*)

Office lighting. Adequate distribution of light in offices and drafting rooms has long been recognized as an indispensable facility, although it is still being neglected in old-fashioned buildings. The lighting must not only provide the needed intensity but must also be of the proper quality. Excellent lighting throughout the offices may be provided by continuous-row fluorescent fixtures, such as shown in Figure 170. Fluorescent lighting is generally favored for office areas. Photoelectric controls vary the amount of lighting as the intensity of natural light changes. Shadows are almost entirely absent from these lights, and there is virtual freedom from glare. Such excellent illumination not only helps the office force do more and better work, but it also reduces fatigue.

Heat and ventilation. To get work done efficiently in an office, there must be a proper control of temperature and ventilation. All radiators should be thermostatically controlled, to avoid either overheating or underheating when individuals have free access to the radiator valves. It is desirable that the ventilation system be capable of providing a complete change of air at least four times an hour during the work day. In some geographical areas, humidity control is equally important.

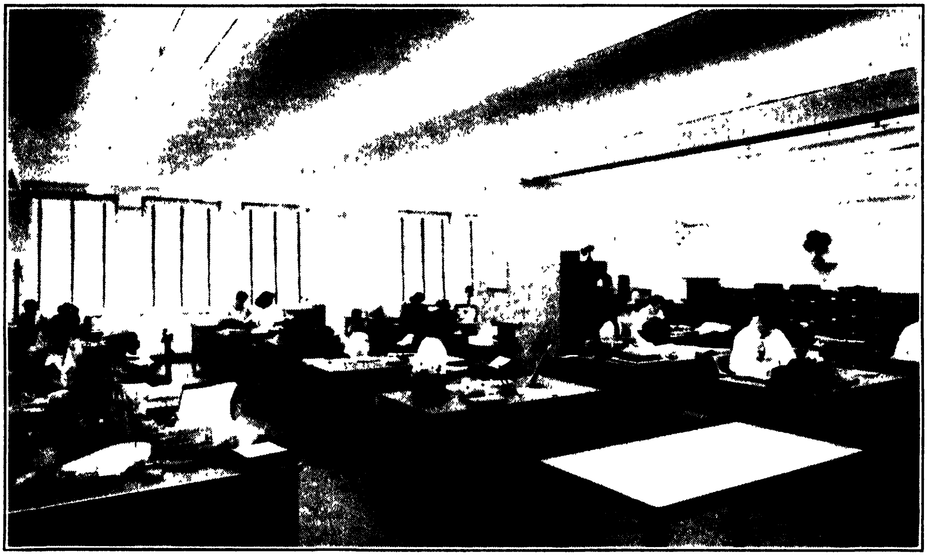


FIG. 170. *Fluorescent lighting* is generally favored for office areas. Excellent lighting, free of shadows and glare, may be provided throughout the offices by continuous-row fluorescent fixtures such as are shown in this photograph. (*Courtesy of U.S. Gypsum Company.*)

Electrical outlets in an office are frequently at a premium. As a result, the outlets become overloaded with wires plugged in for the operation of office machinery or desk lamps. In laying out an office, it is usually better to oversupply the electric-power outlets than to attempt to skimp. Electric conduits should be planned to run under the flooring and to provide a generous number of outlets through the floor surface. When not used, these outlets can be disconnected and dismantled, thus leaving no unused projections from the floor.

Acoustical treatment of office ceilings with sound-deadening paneling has demonstrated its effectiveness through widespread application in recent years. Noise affects many persons in much the same handicapping degree as eyestrain. Reduction of noise has enabled these people to show a decided improvement in the quantity and quality of their office work.

CHAPTER XIX

Employee Service Facilities

1. PLANT APPROACH, PARKING LOTS, AND PLANT ENTRANCES

Mounting Importance of Working Conditions

Providing a work place that would keep employees contented and comfortable received widespread attention before World War II. This was an outgrowth of management's awakening to the mounting importance of good industrial relations with employees. When it is realized that a person working 8 hours a day in an industrial plant spends nearly one-third of his adult life in the plant, the importance of adequate service facilities is readily appreciated. The wartime employment of millions of workers without any previous contact with industrial plants gave rise to new layout problems. The postwar decentralization of industry finally raised the subject of employee facilities to a level comparable in importance to the layout of the production facilities of the plant.

Major emphasis is being placed on those factors which conserve man-hours and energy; lead to the efficient use of space; and make the plant comfortable, clean, safe, sanitary, and attractive. To insure the best working conditions for its office employees, the management in many companies has gone beyond the minimum provisions for office facilities. An engineering approach to the satisfactory solution of problems of employee facilities has thus become just as essential as it is to production layout.

Landscaping

Growing in pace with management's recognition of its broad responsibility for employee health and welfare is the interest in the over-all appearance of the plants. Industrial executives have come to realize that lawns and landscaping are just as important as the architectural design of the plant buildings. An illustration of the lawns and landscaping surrounding the plant buildings in General Electric's electronics park at Syracuse, N. Y., is shown in model form in Figure 171. The appearance of the plant is enhanced by the spaciousness of the grounds, the arrangement of the trees and shrubbery, and the network of landscaped roadways and walks.

Parking Lots

Consideration must be given to every factor that impedes traffic movement at the approaches to the plant as well as within the plant property. The proper design of parking lots with relation to traffic handling and ease of access to plant gates is important in building the goodwill of employees. The parking lot must

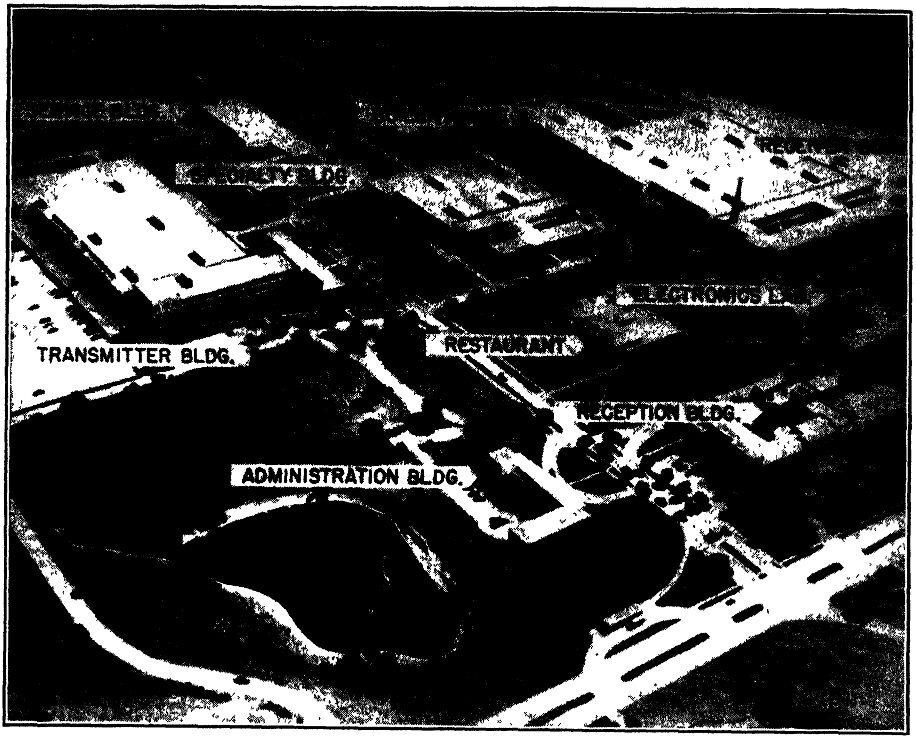


FIG. 171. *Lawns and landscaping.* Scale-model layout of the buildings and grounds of the General Electric Company's electronics park at Syracuse, N. Y.

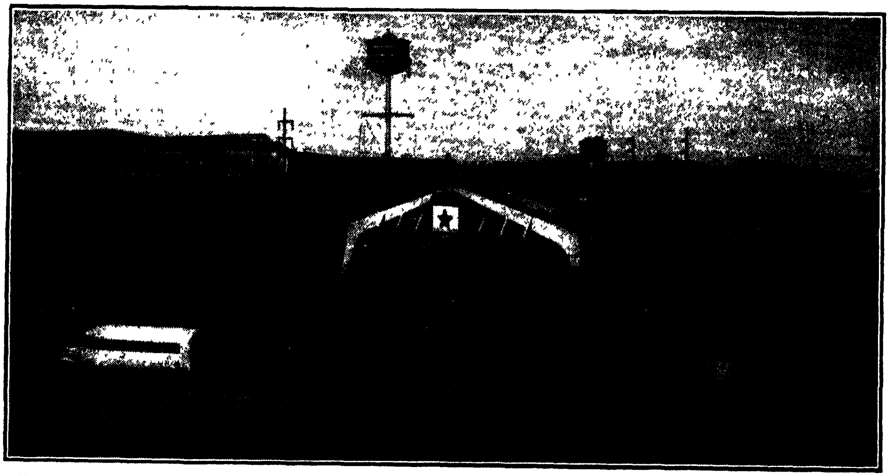


FIG. 172. *Employees' entrance* at Boeing Aircraft plant at Wichita, Kan. Bus depots and overhead ramps permit the movement of large numbers of employees with comparative safety and with full protection from the weather. (*Courtesy of the Austin Company, Cleveland.*)

be integrated with the street and highway system serving the plant so as to permit smooth handling of periodic traffic congestions. Where adequate parking accommodations are located within a short walking distance of the plant, employees experience no lost time or marred tempers in beginning or ending a day's work.

Plant Approach

In plants served by public vehicles, passenger loading platforms located at strategic points may greatly relieve pedestrian congestions occurring at the start and end of each shift. Ease of entrance to, and exit from, a plant occurs only when the plant approach, parking lots, and gatehouses are all integral parts of the plant layout plan. An example of a well-planned plant approach and entrance is given in Figure 172. Although executed on a comparatively elaborate scale for the handling of thousands of employees at a war plant, the arrangement in principle can be adapted to suit the requirements of a plant employing less than 1,000 employees.

FIG. 173. *Employment office.* Partitioned cubicles, an acoustic ceiling with recessed lighting, plus an asphalt-tile floor and plastered walls convey an air of refinement and progress to the job applicant entering this plant for the first time. (*Courtesy of the Austin Company, Cleveland.*)

Employment Office

The first impression a job applicant gets of the efficiency of the plant organization he is seeking to join is usually in the employment office. Inasmuch as first impressions are considered lasting ones, growing attention has been given to the modernization of this entrance office. A modern conception of what this type of office should be like is given in Figure 173. Bank-type wall counters have been provided on the left of the office for the convenience of applicants filling out blanks. Partitioned cubicles are located on the right, across the lobby. An acoustic ceiling with recessed fluorescent troffer lighting, plus an asphalt-tile floor and plastered walls, give this office the final touch in dignity and efficiency.

Pedestrian Traffic

Other points to consider in planning entrances and exits for industrial buildings, in so far as good plant layout dictates, are the following:

1. Doors should always open out. Doors that are likely to be used as emergency exits should be equipped with panic hardware.

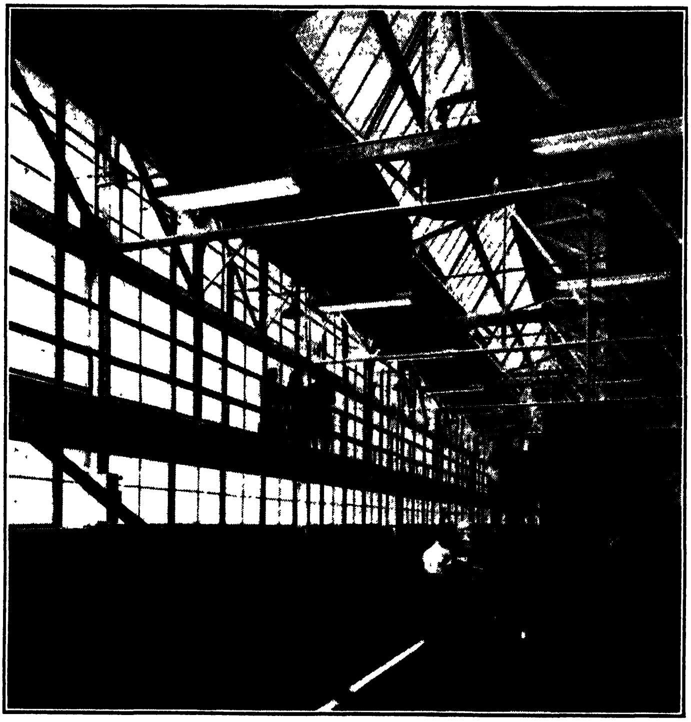


FIG. 174. *Overhead walkway* to segregate pedestrian traffic from main traffic aisles at Thompson Aircraft Products, Inc., Euclid, Ohio. This arrangement permits a greater utilization of main-floor space for manufacturing activities, while also providing better safety for foot traffic. (*Courtesy of Albert Kahn Associated Architects and Engineers, Detroit.*)

2. Wide stairs and ramps should be bisected by a center rail to divide traffic and provide safety in periods of congestion.
3. "Blind spots" on turns in hallways and passages should be eliminated through the use of mirrors at the turning angle. Pedestrian traffic should be protected against vehicular traffic (Figure 174).
4. Time clocks, card racks, package depositories, etc., used by the employees should be located in gatehouses or other strategic points along the normal path of travel followed by the employees in checking in or out of the plant (Figure 175).

2. CAFETERIAS, LUNCHROOMS, AND KITCHENS

Trend to In-Plant Feeding

The trend to locate plants in outlying areas has probably been the largest single factor in establishing permanent recognition of the need for in-plant feeding. In the system where lunch wagons are brought in from outside, the wrapped sandwiches and coffee they provide are frequently cold. Lunches brought from home are cold and often are not sufficient or well-prepared from a nutritional standpoint. When outside restaurants are too far from the plant, the workers cannot patronize them because of the limited duration of the lunch period.

Fig. 175. *Time clocks* should be located inside the work areas along the normal path of travel and adjacent to the entrances to locker rooms, if not too distant from the gate-house. (*Courtesy of the Austin Company, Cleveland.*)

The opportunity to purchase good, wholesome food at a reasonable cost at the plant has already been enjoyed by a broad proportion of America's industrial population. So much so, in fact, that many industries which do not already have their own cafeterias are making definite plans for them in the immediate future. This is true in urban as well as outlying locations, and applies generally to firms employing 300 or more persons on a single shift

Determining Size and Type of Cafeteria

Cafeterias range in size from a seating capacity of 100 up to 2,000 or more persons, depending on the size of the plant force. Some cafeterias operate mobile units, as shown in Figure 176. The other extreme is the large auditorium which, when used as a cafeteria during working hours, can seat approximately 2,000 persons.

Factors to be considered in determining the type and size of cafeteria suitable for a given plant include the following:

1. The proximity to outside lunchrooms or restaurants.
2. The number of workers on each shift.

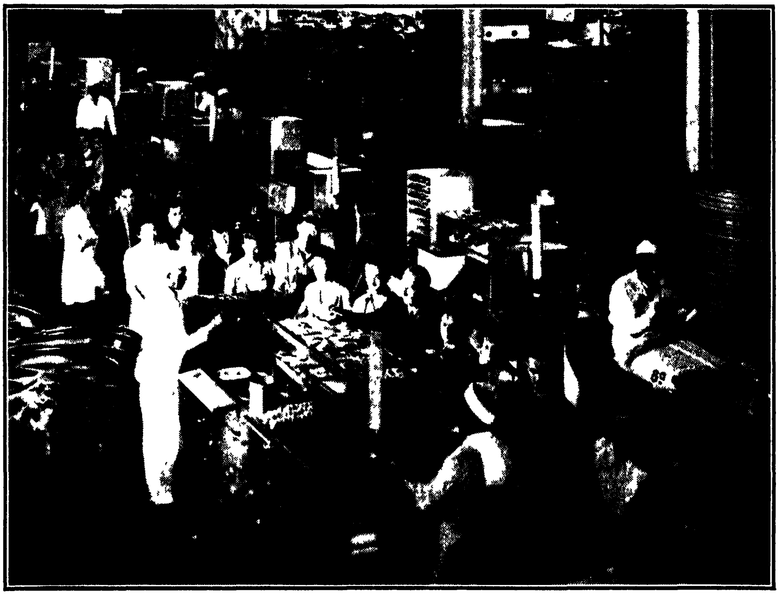


FIG. 176. *Mobile kitchen unit* in the plant of the Boeing Aircraft Company, Wichita, Kan., moves through the shop to serve the workers in their work areas. The unit is equipped with both hot and cold chambers. A train of similar kitchen units, seen in the background, is being hauled by an industrial tractor to be deposited at strategic points through the shop. (*Courtesy of the Austin Company, Cleveland.*)

3. The number of meals to be prepared.
4. The length and number of lunch periods.
5. The plant area available for catering use.
6. The distribution of employees throughout the plant.
7. The desirability of leasing out the cafeteria to a restaurateur and enabling him to make a profit.
8. The views entertained by the employees and their union.
9. The possibility of using the cafeteria room for joint purposes, such as a classroom, meeting room, recreation room, or auditorium.
10. The economies of providing a plant kitchen as against securing the food from a caterer.
11. The desirability of setting up a "sandwich line" to expedite the flow of customers through the "full meal" line.

12. The desirability of segregating the sexes or of making added provisions for office employees.
13. The desirability of enclosing a section of the cafeteria for a private dining room for executives and visitors.

Plant cafeterias and canteens during their wartime peak served hundreds of thousands of persons daily. Experience in the design and layout of these facilities shows that a careful analysis of the feeding problem is just as important in the small plant as in the big one. An example of a 150-seat cafeteria is shown in Figure 177.

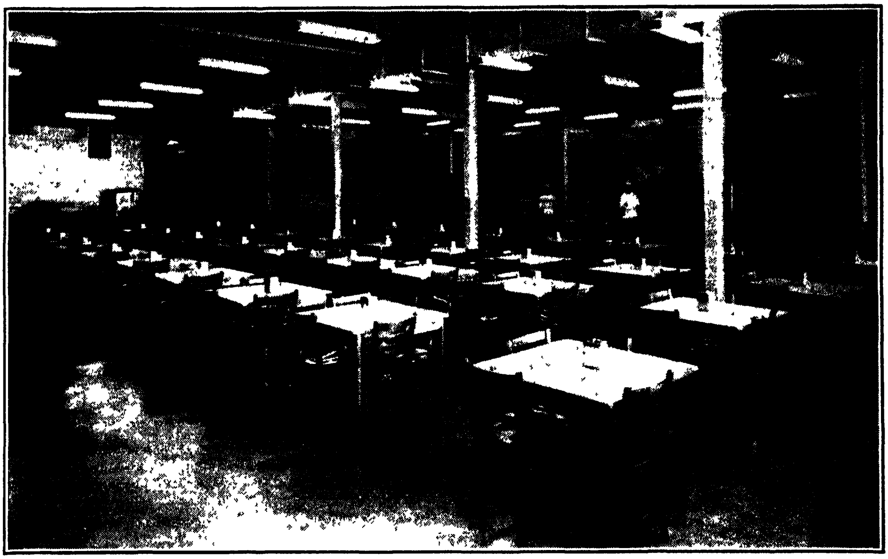


FIG. 177. *Cafeteria seating 150 people* in the plant of the Humboldt Full Fashioned Hosiery Mills, Humboldt, Tenn. (*Courtesy of Lockwood Greene Engineers, Inc., New York.*)

Glazed-tile walls, asphalt-tile flooring, acoustic ceiling, fluorescent light fixtures, and ventilation are commonplace features in modern cafeterias independent of the seating capacity. In most cases, wide column spacing which permits maximum efficiency in the seating and routing of customers has been found desirable. This spacing also adds considerably to the appearance of the cafeteria room.

Flow Chart of Serving Lines

To determine the most suitable type of facility, it is well to prepare a flow chart such as illustrated in Figure 178. This should be done before final plans are made for the food-serving program. In the end, it will be found necessary that the food production line approach the smooth operation aspects of an industrial assembly line. The serving counter, such as the one illustrated in Figure 179, is the crux of the entire cafeteria layout. For that reason, it is essential to consider whether one serving unit, such as the one illustrated, will be sufficient or whether there should be two or more identical serving units in order to attend to a corresponding number of serving lines at one time. There is also the problem of converging these separate serving lines towards a lesser number of cash registers.

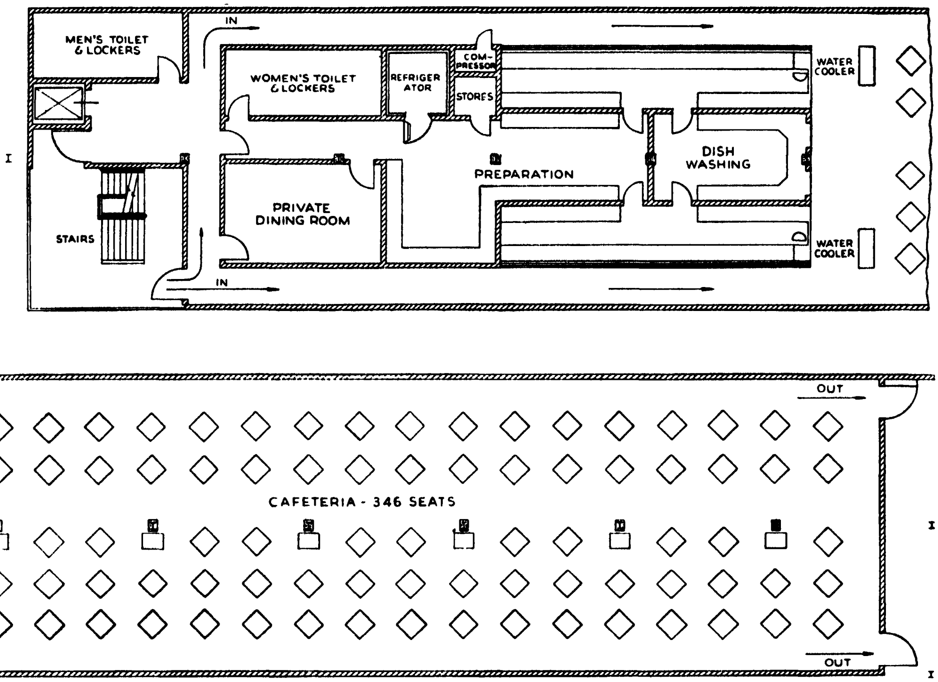


FIG. 178. *Arrangement of proposed cafeteria,* second-floor service bay, for new turbine building, General Electric Company, Schenectady, N. Y. (*Courtesy of Stone & Webster Engineering Corporation, Boston.*)

Laying Out the Kitchen

The kitchen layout is devised to minimize the handling of food, and to reduce the possibility of contamination. The first point to consider, as in any cafeteria layout, is the location of the kitchen. When there is not enough space available in the plant, at centers of worker force, for both the kitchen and the cafeteria, it may be necessary to separate these two activities. A logical place to locate the kitchen, wherever permissible, is where it will be convenient for receiving raw foods without interfering with production.

In the kitchen layout, provision must be made for food storage, utensils, ranges, refrigerators, and preparation tables. The flow of meat is from the refrigerator, over the preparation tables, and onto the stove, in the direction of the cafeteria. The section used for vegetable preparation may be in another direction, through a vegetable storage refrigerator, through proper vegetable washing sinks, and onto the stoves to join the meat as it finds its way to the cafeteria.

Staples are usually handled through a storeroom. The sandwich preparation area in the kitchen is usually adjacent to a special refrigerator in which salads

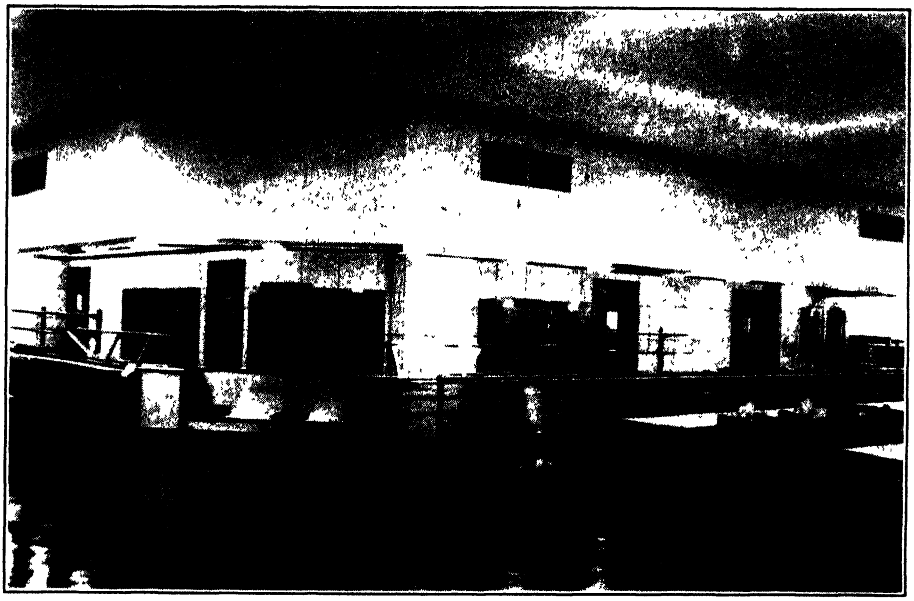


FIG. 179. *Serving counter for 600-seat cafeteria* in Detroit plant of the U.S. Rubber Company. The cafeteria has tan-and-maroon terra-cotta wainscot, plastered walls, and an asphalt-tile floor. The flush-type fluorescent lighting is recessed into the acoustical-tile ceiling. (*Courtesy of Lockwood Greene Engineers, Inc., New York.*)

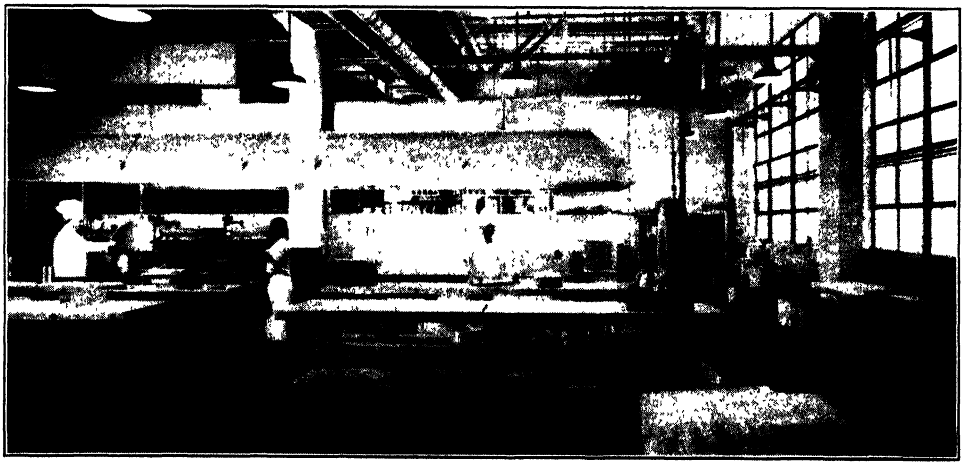


FIG. 180. *Portion of kitchen,* about one-quarter, where meals for the 400-seat cafeteria of the Emerson Electric Manufacturing Company are prepared three times a day. The main range extends the full length of the hood, shown here in the background. All the walls are surfaced with glazed tile to expedite wall cleaning. (*Courtesy of the Austin Company, Cleveland.*)

and sandwich material are stored. This allows the preparation and wrapping of sandwiches before they are taken to the cafeteria. A portion of the kitchen serving a 400-seat cafeteria is shown in Figure 180. In addition to the equipment already mentioned, consideration must also be given to the desirability of providing a refrigerator room and a cold-freeze room adjacent to the kitchen.

3. FIRST-AID STATIONS AND MEDICAL DEPARTMENTS

The worker's health in a plant may be protected by three major services: (1) nutritious food, (2) medical services, and (3) employee safety.

Medical services is the factor of immediate concern in this section. These services may be roughly classified in three ways:

1. Examination of applicants.
2. First aid for minor injury or minor illness.
3. Medical department for major injury or major illness.

Job Applicants and First-Aid Patients

Personnel buildings are usually provided with facilities for registration and interviewing of applicants, identification recording, and medical examinations. Interviewing and medical examining rooms are frequently laid out so as to permit the segregation of male and female applicants without requiring duplicate installations of costly medical equipment. Another step taken to avoid duplication of equipment or medical personnel is to place in close proximity the facilities for handling applicants and first-aid patients. In order to prevent the intermingling of applicants and patients the examination area is separated from the treatment area, and each area is provided with its own entrance.

First-Aid Stations

First-aid equipment varies in extent from a medical kit, blanket, and stretcher, kept in closed wall cabinets in different locations in small plants, up to glazed-tile rooms fitted with costly medical equipment. An efficiently equipped first-aid station is shown in Figure 181.

The modern first-aid station or dispensary includes, in many plants, such facilities as a surgery complete with operating and sterilizing apparatus; a treatment room with immunization facilities; a ward containing two to four beds; and ultraviolet and infrared lamps. Two of the more important functions of the dispensary are the control of occupational diseases and the frequent examination of working hazards in the shop. A productive worker must be kept at good health standards to enable him to meet work schedules.

Medical Department

A fully equipped medical department, on the order of the one illustrated in Figure 182, may consist of a network of several rooms which should be laid out according to the flow of patients reporting for treatment. The medical department of the Cadillac Division of the General Motors Company consists of the following collection of 28 rooms inclosed within one area. To facilitate reference, these rooms are listed in alphabetical order:

2 consultation rooms
2 doctors' offices
3 examination rooms
1 eye room
1 hydrotherapy room
1 infection room
1 laboratory
1 nurse's room
1 operating room
1 physiotherapy room
2 record rooms
1 secretary's office
1 soundproof room
1 stockroom
1 throat room
1 treatment room
2 waiting rooms
2 ward rooms
1 X-ray dark room
1 X-ray file room
1 X-ray room

Total rooms 28

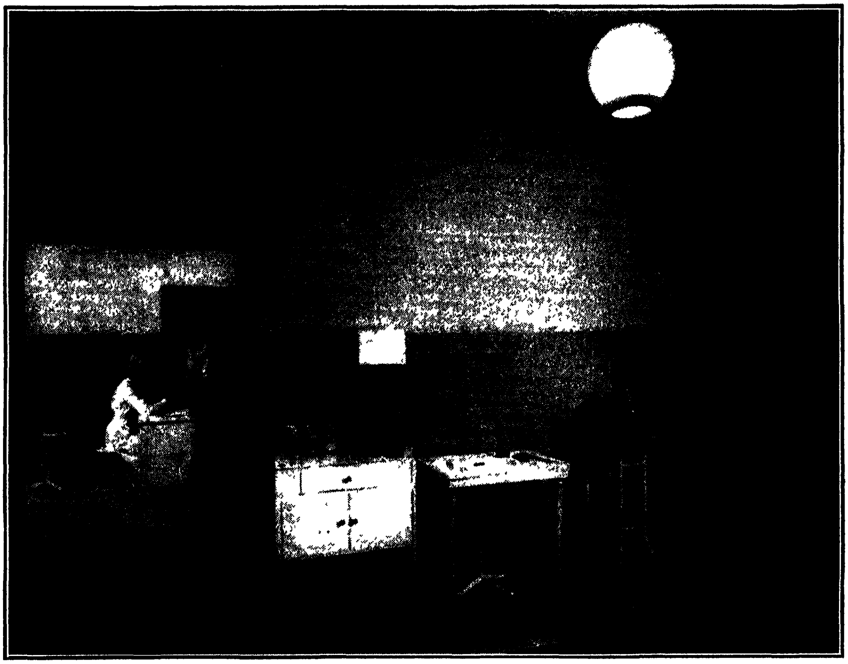


Fig. 181. *First-aid station* at Oklahoma plant of the Douglas Aircraft Company. A buff glazed-tile wainscoting, a terrazo floor, and plastered walls and ceiling insure immaculate cleanliness. (*Courtesy of the Austin Company, Cleveland.*)

In addition to these 28 rooms, the layout also contains 6 dressing booths, 4 toilets, 1 shower, 1 linen closet, and 1 janitor's closet.

To lay out these 28 rooms and 13 adjuncts, the Cadillac plant layout engineers made use of process flow charts for minor injury cases, major injury cases, and preplacement examinations.

Layout of Medical Department

Only when several rooms are involved does a medical department give rise to a layout problem. For plants with less than 300 employees, a first-aid dressing station, plus a men's ward and a women's ward, are considered sufficient. In plants employing from 300 to 1,000 employees, the rooms are the same as for a smaller plant, except that they may be larger and perhaps augmented by a waiting room.

As the plant force mounts into the range of 1,000 up to 5,000 employees, a second first-aid dressing station becomes necessary. This second station is also equipped with its own separate wards for men and women. Additional rooms required for this size of plant include X-ray, therapy, drug, examining, and record rooms.

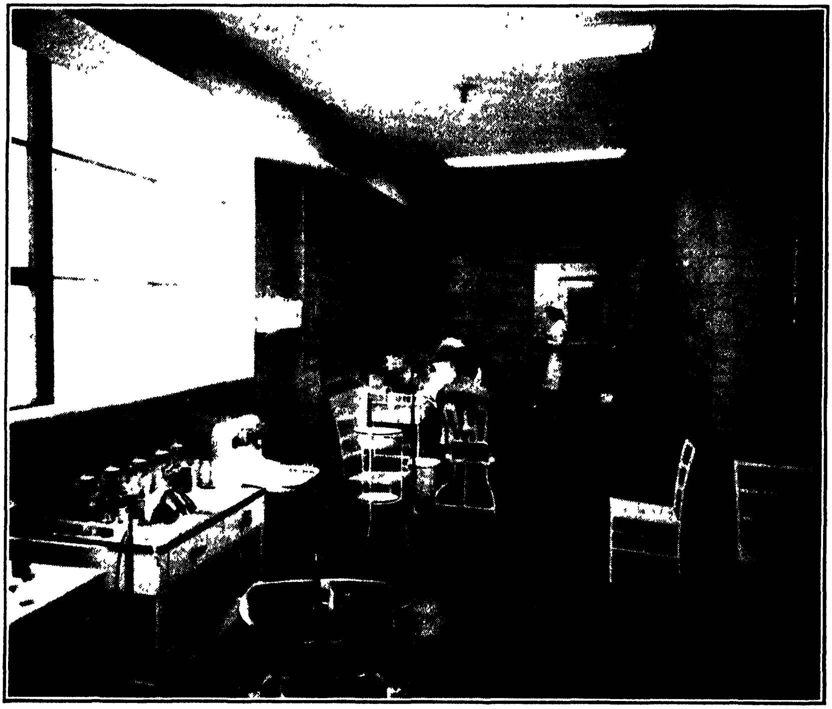


FIG. 182. *Medical department* installed in a location that is central to all portions of a Bell Aircraft Corporation plant. This view, from the main dispensary area, shows a section of the office and waiting room in the background Walls throughout the medical department are surfaced with salt-glazed tile which can be readily washed down The floor is covered with asphalt tile, and fluorescent lighting is recessed in the acoustic-plaster ceiling. (*Courtesy of the Austin Company, Cleveland*)

For plants employing over 5,000 workers, a central medical area is usually set up, plus a number of separate first-aid stations located at strategic points throughout the plant. In planning areas of this size, technical guidance should be obtained from health engineers, local hospitals, or the National Safety Council.

4. LOCKER ROOMS, WATER CLOSETS, AND LAVATORIES

Locating Personal Facilities in Populous Centers

To provide the required personal conveniences to plant personnel within close distance to work areas, these conveniences should be placed in widely distributed locations related to the centers of plant population. Without disturbing the over-all layout of production facilities, the locker rooms and lavatories can be placed out of the way, in central work areas, by locating them in basements, on mezzanines, or adjacent to the shop floor.

Drinking fountains and vending machines, however, should be placed in such a way, in populous areas, as not to cause them to become gossip centers or dating posts. By placing these facilities in work areas that are fairly segregated as to groups of men and women, much horseplay and lost time can be avoided.

Some plant layout engineers maintain that the locating of lavatories, first-aid stations, canteens, and like facilities, in lean-to's or other areas away from production aisles is good design primarily because the aisles are thereby kept free of obstructions. It is, as already pointed out, entirely possible to keep the production areas unobstructed and still locate these facilities in work-force centers, by resorting to overhead or subfloor space. The fact that an employee's time is just as valuable to the plant whether he is at his work station or wandering back and forth to toilet rooms should not be overlooked in laying out production areas and employee facilities.

FIG. 183. *Locker and wash-fountain layout,* one of a number of similar layouts distributed at strategic points around the engine plant of the General Motors Corporation, Indianapolis. The upper level is taken up by urinals and toilets. The lockers are arranged back to back, two tiers high, on both sides of the circular wash fountains, thereby eliminating the need for partitions. (*Courtesy of the Austin Company, Cleveland.*)

Improved Standards in Lavatories

Improvements in materials, equipment, and lighting and ventilating practices in recent years have raised the standard of toilet facilities in industrial plants to a level which, only a few years back, was reserved for first-class hotels and public buildings. An example of current high standards for locker rooms, water closets, and lavatories is given in Figure 183. Every worker has his or her own steel locker in one of the groups lined along the sides of the washroom. Circular mottled-stone wash fountains, or batteries of individual wash basins, all in the center of the rooms, provide modern washing facilities to which old-time employees were not accustomed.

Wash fountains are usually supplied with special containers for high-quality powdered soap, thereby eliminating the clogging of drains by soap-cake remnants. An extra touch in the direction of cleanliness is sometimes given by placing a germicidal lamp near the wash fountains to help destroy cold germs and the like. A rubber trough mat, containing an antiseptic solution for the feet, may be supplied at the entrance to shower stalls. In brief, nothing is overlooked which promotes good health and sanitation.

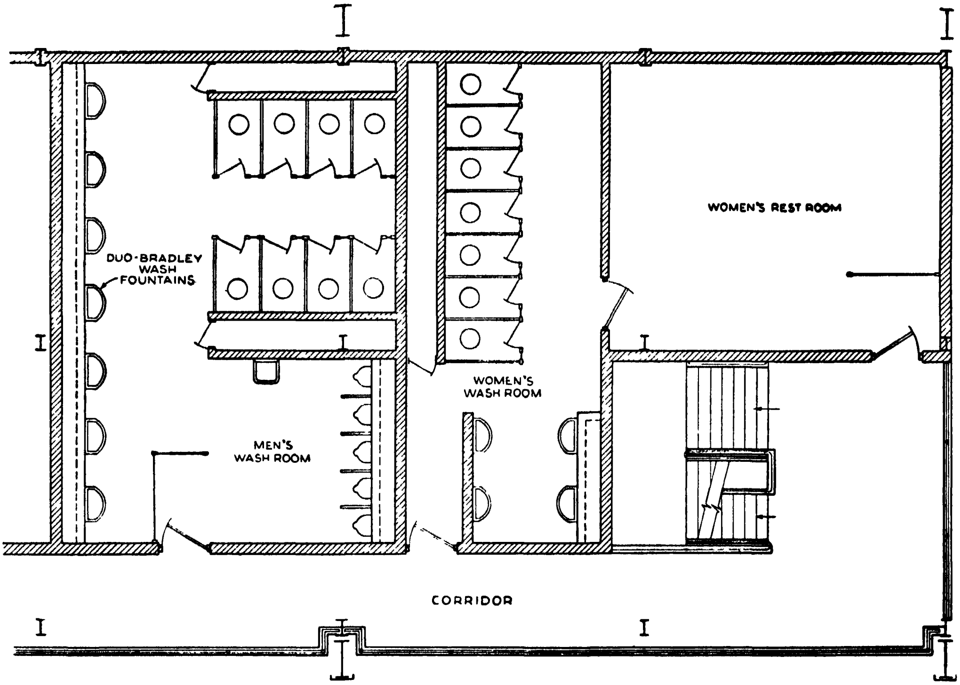


FIG. 184. *Arrangement of men's and women's washrooms* for personnel in new turbine building, General Electric Company, Schenectady, N. Y. (*Courtesy of Stone & Webster Engineering Corporation, Boston.*)

Washroom floors in modern layouts, as illustrated in Figure 184, are often covered with tile, whereas the sidewalls and partitions are made of clear glazed tile, even with a cove base. Overhead, a thermostatically controlled unit heater is usually included to keep the locker-room temperature at a level that is comfortable for disrobing and washing.

Rest rooms for women have become a common institution in many plants. Such rooms usually combine the functions of a locker room and snack room, particularly for office women. The rest room may be equipped with an electric refrigerator, a cabinet sink with dishes, and an electric stove. Other furniture that may be included is a dinette set, a studio couch, and pieces of rattan furniture. Thus equipped, the room gives the appearance of a cozy, well-furnished little apartment.

PART 4 · JUSTIFYING THE PLANT LAYOUT

CHAPTER XX

Buildings for Housing the Plant Layout

1. PLANT MODERNIZATION VERSUS PLANT CONSTRUCTION

The need for modernization, expansion, or a new plant is not so obvious, although perhaps more urgent, in some industrial companies as in others. When existing plants cannot produce enough goods to satisfy the demand or when costs are high because the buildings do not allow effective layouts, the need for new facilities cannot be questioned. The enterprise that allows its competitors the advantages of improved methods, equipment, and plant layouts is developing the handicap of inefficiency. On the other hand, the company that keeps up with progress places itself in the lead of competition.

Many a plant building over 40 years old, although well constructed and still in good condition, lacks the new ideas and principles that have increased production efficiency many times in the newer plants. The plant may have been built in the days when a factory building was erected on any plot of ground that could be bought at a low price, regardless of the adequacy of its size or shape. The processes were then fitted to the structure. without anticipation of present-day high operating costs.

Cutting Costs through Re-Layouts

Since the time of those less competitive days, factory layout has been developed from vague notions to scientific principles. The output of machinery has been stepped up continually. Material-handling equipment, capable of reducing costs beyond all expectations in those old days, has become commonplace in modern plants. Laws have imposed new sanitary codes and other regulations. All costs have gone up tremendously, and many of them are held at high levels by labor laws or economic conditions. Competition in the meantime has become more acute each year.

There can be no question of the need to reduce these costs. One of industry's most effective tools in cutting production costs is a properly laid-out plant. Prominent among the many ways open to reduce costs are layouts that permit greater efficiency of plant operation; better facilities for handling and storing raw materials and finished products; and provisions for worker health and comfort to promote high morale and efficient productivity. Aside from the fixed limitations of length, width, height, and number of columns, there is not too much about the plant building that cannot be altered to adapt it to the important requirements of modernization. It can, as a rule, be fitted out with most of the conveniences found in modern factory buildings.

Rehabilitation of Existing Plant

In any program of rehabilitation, one of the first steps is to ascertain the structural soundness of the building. Foundations, columns, footings, walls, and roof decks must be examined for signs of weakness. Installation of additional equipment will, of course, increase floor loadings. Floors frequently cause more trouble than any other element of a plant building. Changes in the location of departments or in the character of the processes often impose on floors more severe loads than they were originally intended to carry.

Decisions as to whether to modernize or build a new plant are relatively simple when the existing plant is too small, maintenance costs are excessive, rent is too high, or rehabilitation measures involve prohibitive cost. Under these circumstances the choice is in favor of a new plant. With other conditions decision becomes difficult. In the interest of low-cost production it may or may not be economically sound to invest in a new structure. Perhaps the disadvantages of the present location may justify a new plant in a different location. The need for either centralization or decentralization may also point in the direction of a new plant.

Cost of New Construction

An important deterrent in deciding to build a new plant today is the current high level of construction costs. The ingenuity of experienced architects and builders can usually develop ways of getting around many of these costs, however (see Figure 185). In the face of shortages in building material and labor, many enterprises formerly intent on building new plants have been forced to consider modernizing existing plants. The working out of effective modernization plans to add production efficiency to available structures presents problems of manufacturing which must be dovetailed into the knowledge of the architect, plant layout engineer, and contractor. Where the principal problems are not directly related to capacity or layout and do not involve rearranging the flow of production, adding material-handling equipment, or expanding employee or service facilities, temporary measures usually suffice.

As a general rule, alterations and additions cost considerably more than outright new construction involving comparable quantities and types of materials. In the final analysis, therefore, it is largely a question of how much better a new plant will do the job than the old one, no matter how the latter is rehabilitated.

2. INFLUENCE OF SITE LIMITATIONS ON THE PLANT LAYOUT

Expansion of Enterprises.

Most manufacturing enterprises begin operations on a modest scale, usually in rented space in an existing building. The large manufacturing industries are usually the outgrowth of one or more small plants, which have expanded on the initial premises or may have moved to new locations as the business expanded. Large industries have also been formed by merging the activities of small enterprises or by progressive additions made to accommodate new lines of production, new productive departments, or additional service facilities.

At various stages during their expansion, therefore, manufacturing enterprises require additional space and rearrangement of productive facilities. When plants outgrow the space available in existing premises they are compelled either to invest in a new location or, failing to raise the necessary capital for this move, remain at a standstill, which frequently leads to extinction. Limited capital is often the reason for enduring site restrictions, particularly when adjoining space is available. Occasions exist where, with the necessary funds available, the planning of this expansion has not always been developed to the point of reflecting properly the soundness of the investment involved.

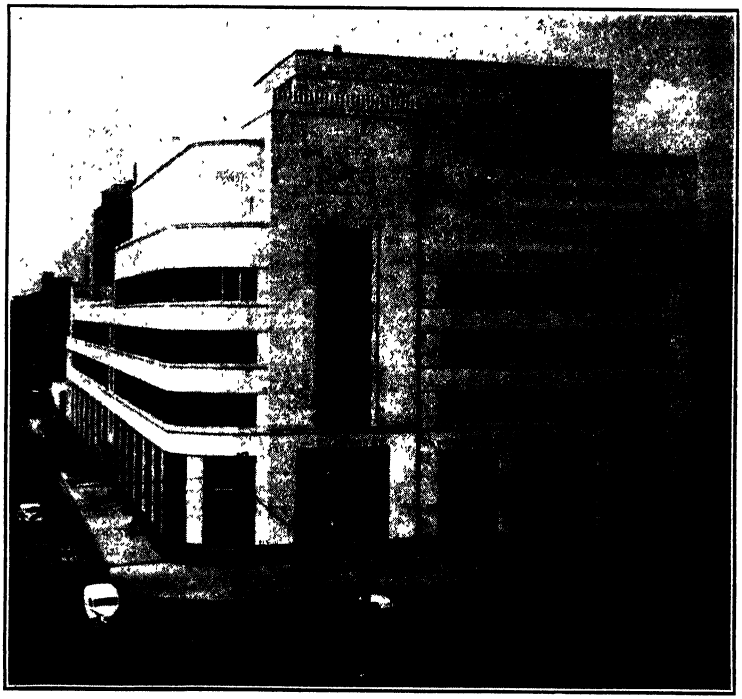


FIG. 185. *Two buildings in one.* Although giving the appearance of one building, this plant of the *Courier-Journal* and *Louisville Times*, Louisville, Ky., actually consists of two independent structural units. The front unit of seven stories houses the offices and radio studios. The rear unit of four stories (on the left) is the newspaper plant. The purpose of this structural segregation is to keep the noise and vibration of the newspaper plant out of the offices and studios. (*Courtesy of Lockwood Greene Engineers, Inc., New York.*)

Site Restriction Problems

In selecting a site and locating buildings on this site, proper planning for future expansion can eliminate many of the site restrictions that so often develop as an enterprise expands. Such a handicap as the lack of flexibility in a multi-story building might have been eliminated by the selection of a single-story plant in the beginning. Moreover building widths, column spacings, foundations, clear spans, etc., when planned with foresight in the original buildings, are not likely to present site-restriction problems as the plant develops into greater volume and broader lines of activities over the years of normal growth.

The modern printing plant of the Standard Register Company at Dayton, Ohio, shown in Figure 186, has reached its present size and layout through ten successive additions made over a 30-year span. Although located within city limits, the original site of this enterprise was selected with enough room for future growth to permit the evolution of the sprawling group of buildings shown individually in Figure 187.

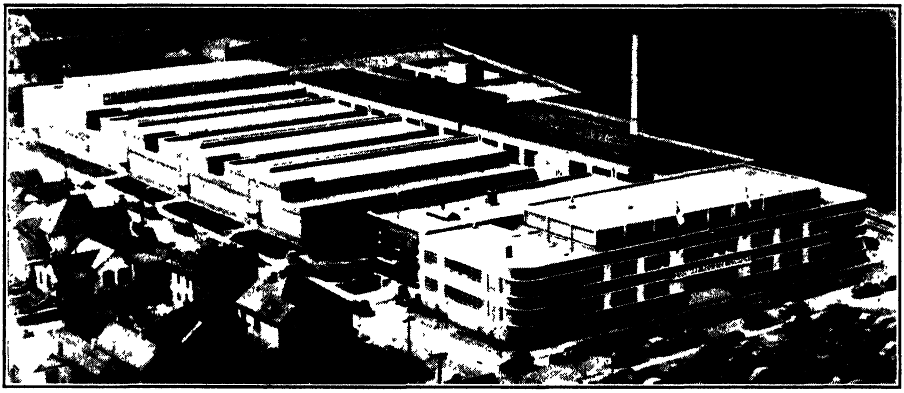


FIG. 186. *Modern printing plant* of the Standard Register Company, Dayton, Ohio, after ten successive additions of buildings on original premises. Note the chronological steps of expansion shown in Figure 187.

Preliminary Layout Preceding Site Selection

In planning the layout of a building the plant layout engineer should visualize on paper what the fully developed site will look like years later when the enterprise has expanded. Such plans, incidentally, may conceivably provide a ready basis for emergency expansion in case of war. Accompanying the expansion of buildings on these plans should be projections of site developments in the form of storage yards, parking lots, railroad sidings, driveways, lawns, outbuildings, and service facilities. (See Figure 110 on page 225.)

A sound check on the suitability of a site can be made by designing a tentative layout of the proposed plant based on process requirements of floor space independent of site dimensions. This preliminary design of the type of plant layout most suitable to the operations affords a sound criterion for selecting a site and for locating the first building on this site. Before the final layout is made, however, the site must be acquired so as to permit the layout to be fitted to the site. Not until the site boundaries are known definitely can the final layout show storage yards, parking lots, railroad sidings, and other site developments previously mentioned.

Site Data Required for Plant Layout

Another important step to take before the final plant layout is drawn up is to inspect the site. Boundary dimensions are shown on a contour map. Also needed is the location of the railroad tracks, waterfront if any, and highways bordering on the property or adjacent to it. A complete record of the location, size, and elevation of sewers, water mains, electric services, gas mains, and purchasable steam is likewise essential. If the plant processes emit fumes or possess hazardous features, a full review should be made of state and local codes regarding plant safety, sanitation, and welfare regulations.

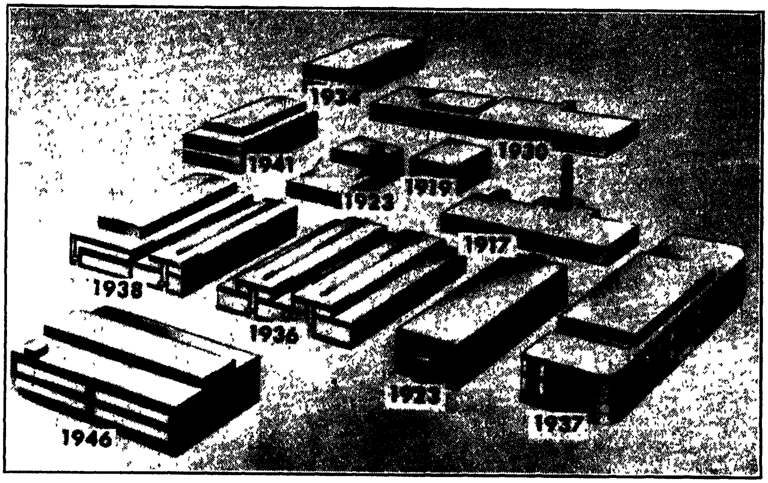


FIG. 187. *Evolution of a plant.* The printing plant of the Standard Register Company pictured in Figure 186 was expanded into its present sprawling group of buildings through the ten successive additions identified above by the years of progressive growth.

The bearing value of the soil on the site is a problem that may prove extremely troublesome and costly. A case in point is a new building which was erected next to an existing plant building. According to the best memory of the oldest employees, the ground was all "solid." For this reason, the engineers' request to make test borings was ignored. When the time came to excavate for column footings, subsoil quicksand was struck along one row of columns. This discovery occasioned an additional expenditure of $16,000 to remedy. This expense could have been saved had the test borings been made. A simple rig for testing soil-bearing value is shown in Figure 188.

3. BLENDING PLANT DESIGN WITH CREATIVE PLANT LAYOUT

The industrial plant building is no longer considered as just a building structure or a place where manufacturing is carried on. The functional design of a building is now more generally recognized as an aid to production itself. It holds intact a processing facility in which materials, labor, and power are converted into products.

Plant layout has become more and more the key to the complex organisms that make up this processing facility. As pointed out in the opening chapter, plant layout functions today as the **blueprint of management.** It is through plant layout that the various processes and operations of a plant are coordinated into an integral production machine, and it is to house this layout that one or more plant buildings are designed.

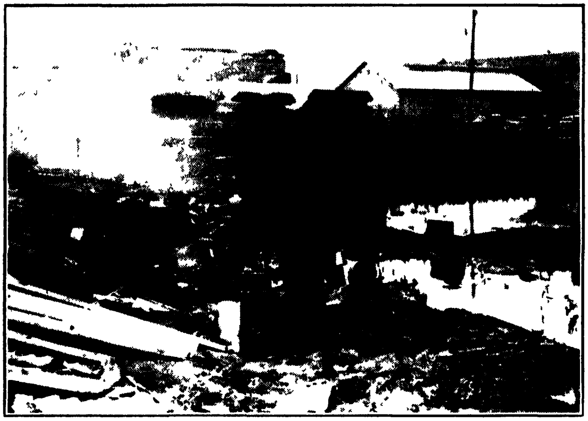


FIG. 188. *Simple rig for testing soil-bearing value.* The platform is mounted on a hardwood post 1 foot square. The load consists of 4,000 pounds of pig-iron ingots. The settlement of the load into the soil is read hourly with a transit to determine the bearing value of the soil

Fitting the Plant to the Layout

The arrangement of machinery, equipment, and service facilities is predetermined in the plant layout to suit the processes and operations. A plant building must now be designed to house the creative layout, and the housing must in turn be shaped to fit around this layout.

The building itself, however, is more than just a shelter for the enterprise. In many instances multi-story floors provide the gravity flows; the supporting columns also support the traveling cranes; the walls and roof condition the material for processing and provide the comfort and health protection that are conducive to high productivity; and the built-in silos, bulk storages, furnaces, pits, ducts, etc., are all a part of the organism of the composite production machine known as a manufacturing enterprise.

On the basis that the primary element to be considered in the design of an industrial plant is the process itself as integrated in the plant layout, let us examine the application of this principle in actual practice. In many bulk-process industries, the processes require a careful layout of flow-line piping to conserve process steam and hold down the cost of waste disposal; otherwise the operating profits are likely to "flow down the sewer." In mass-production industries, the plant layout co-ordinates the activities of machinery, material-handling equipment, and manpower to expedite, control, and economize the conversion of raw material and the assembly of parts into finished products.

The ultimate in plant layout is to plan each process flow and assembly line so that material moves, step by step, along the flow of production, without sidestepping into special processing departments. The continuous routing thus developed in the plant layout becomes a governing factor in designing the building to house this layout.

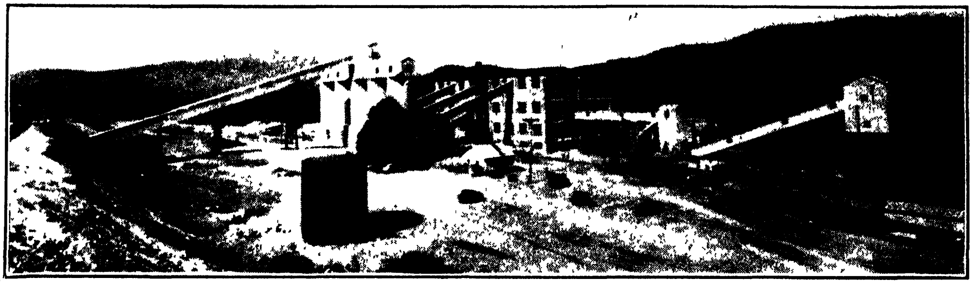


Fig. 189. *Plant designed along a conveyor system* connecting all the buildings in the layout of the Republic Steel Corporation's unit at Mineville, N. Y. From left to right is the track hopper; conveyor to crushed-ore bins; conveyors to concentrate building; and in center right, tailings conveyors. (*Courtesy of the Austin Company, Cleveland.*)

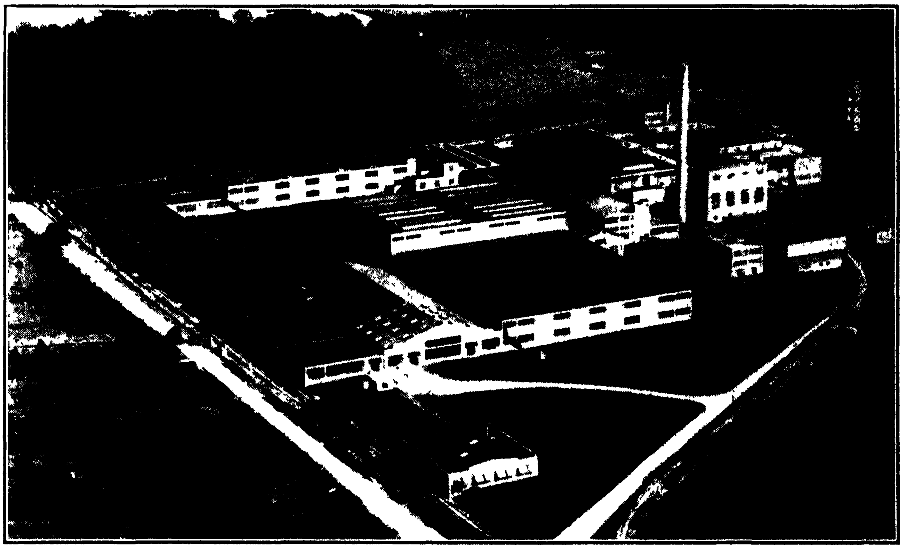


Fig. 190. *Functional layout of linoleum plant* of the Sloane-Blabon Corporation, Trenton, N. J. Structures of various elevations have been laid out in symmetrical pattern enclosed by railroad sidings to facilitate the flow requirements of work in process. (*Courtesy of Lockwood Greene Engineers, Inc., New York.*)

A plant designed along a conveyor system is shown in Figure 189. In this plant, the buildings have been located along the flow of production in such a way that material moves progressively, from building to building, over a system of conveyors interconnecting the various buildings. Another example of a plant designed along functional lines is given in the aerial view (Figure 190) of a linoleum plant.

Study Drawing Made from the Plant Layout

When the plant layout has been properly designed, it should show the best arrangement of processing equipment. From the layout, a study drawing is made, such as the one illustrated in Figure 191, to show in diagram the material-handling systems, process piping, power lines, and offices and service facilities, such as receiving and shipping departments, stores, cafeterias, the medical department, rest rooms, locker rooms, and washrooms. Provisions for plant expansion and site limitations should also be considered in the study drawing.

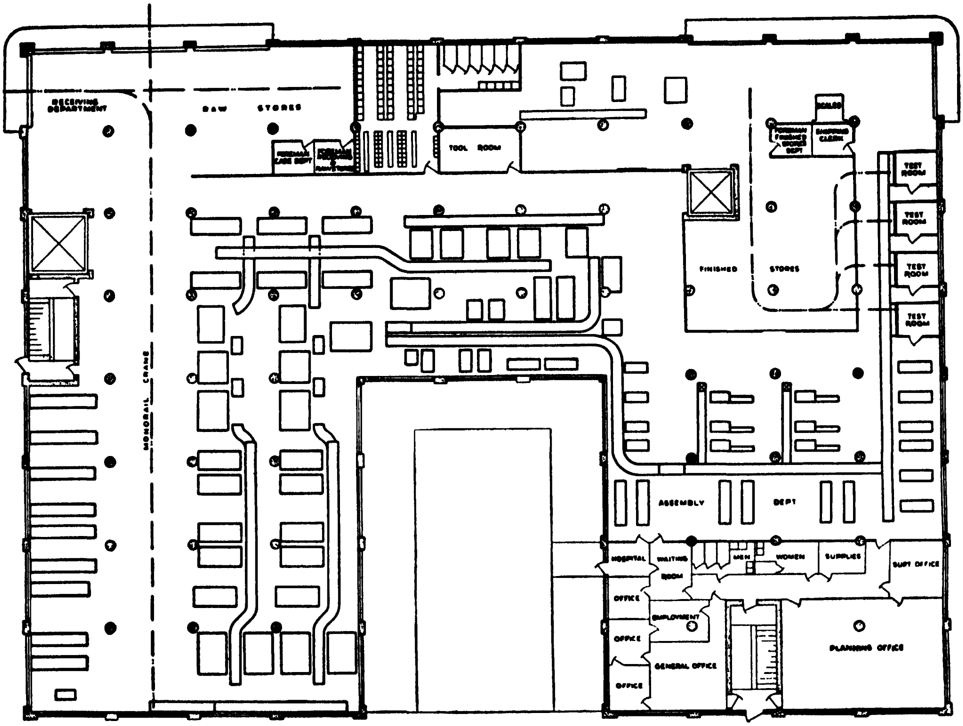


FIG. 191. *Study drawing prepared from plant layout* by Stone & Webster Engineering Corporation, Boston. In this diagram are shown the material-handling systems, process piping, power lines, offices, and all service departments. The type and size of building required to accommodate this arrangement is chosen from this study drawing. (*Courtesy of* Factory Management and Maintenance.)

From this study drawing can be ascertained in preliminary form the type and size of building most suitable to accommodate the arrangement predetermined in the plant layout. Alternate studies of this character are then prepared to make due allowance for outside considerations, such as the shape and topography of the site, climate and soil conditions, local surroundings, and transportation facili-

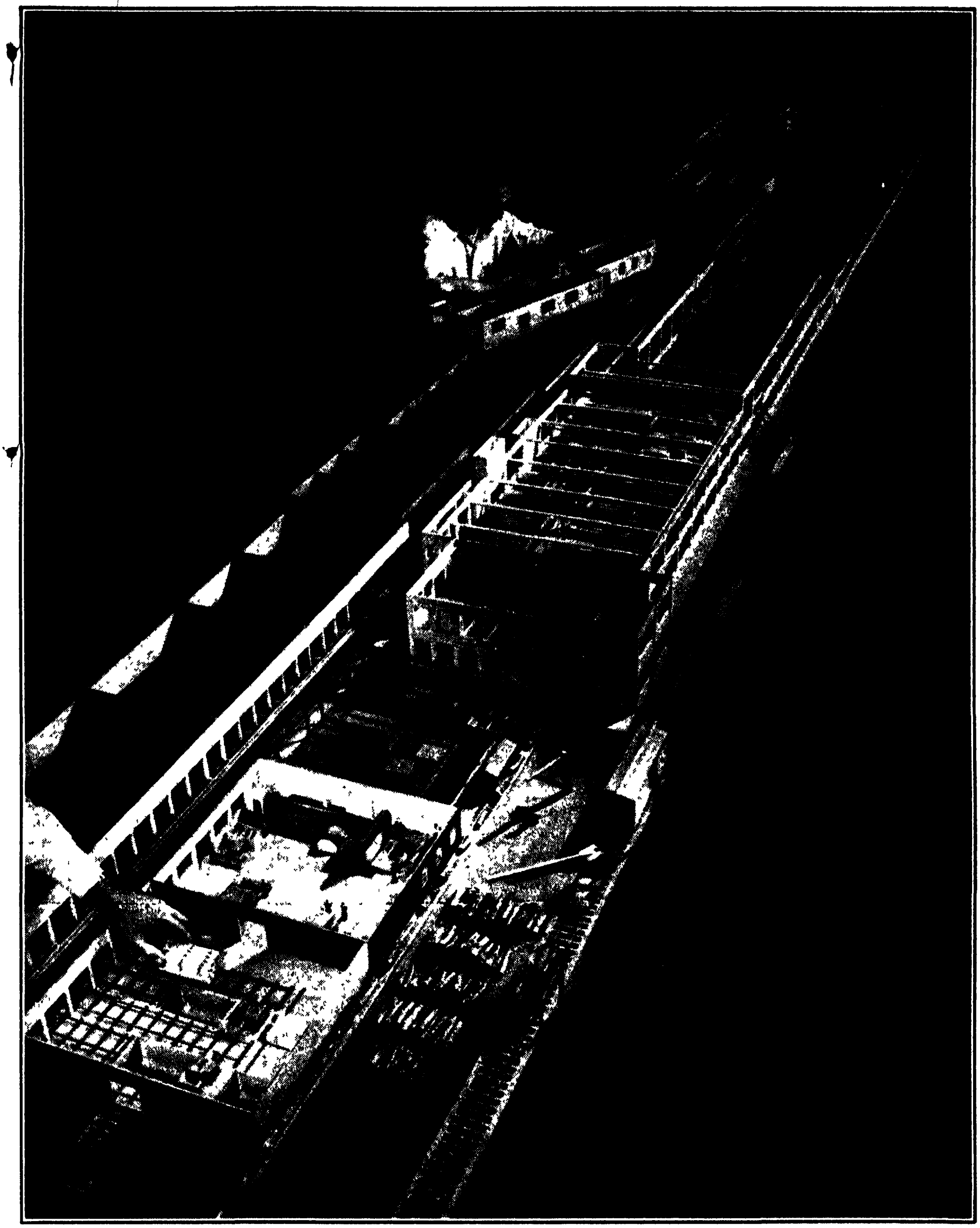


FIG. 192. *Plant expansion in miniature.* Model of the furniture factory of the Lane Company, Inc., Altavista, Va., makers of the Lane cedar chest. Building after building and floor upon floor of machinery, equipment, conveyors, cranes, stacks of material in storage, and operators and workers at their respective work stations present a full panorama of a self-contained Liliputian industrial city bubbling with activity under the eye of the observer. Additional floors or buildings and rearrangements of existing facilities are made in this model years ahead of actual construction. Long-range planning is thus set up as a realistic objective towards which all short-range layout changes are directed, year by year. This view is from the receiving end of the plant where tiny cedar logs are being unloaded from toy-size railroad cars scaled down to ¼ inch = 1 foot, or ⅟₄₈ of actual size.

ties. These alternate studies and outside factors form the basis for determining the design and cost of alternate types and sizes of building required to house the plant layout.

Plant Expansion in Miniature

In making alternate rearrangements of departments, machine groupings, offices, service facilities, etc., for the purpose of choosing the type and size of building best suited for the layout, a miniature model is a convenient medium. The model gives the operating men as well as the engineers an opportunity to visualize the project in a realistic way and to offer constructive suggestions.

Such a model used for planning plant expansion in a furniture factory is shown in Figure 192. Additional floors or buildings and rearrangements of existing facilities are made in this model years ahead of new construction. For purposes of discussion at conferences entire floors from any of the buildings may be lifted intact. Each of these floors is fully equipped with models of machinery and equipment and can be removed to the conference room when it is not desirable to gather the conference around the model.

4. SHAPES AND CROSS-SECTIONS OF ONE-STORY PLANTS

Reciprocal Plans of Plant Layout and Building Design

Alternate study drawings, along the lines of the one already shown in Figure 191, co-ordinated with the finished plant layout, site limitations, and other characteristics of the locality, form the basis for designing the building. This basis is used for considering not only the type and size of the factory building but also its shape, that is, the contour of its base plan lines. By the same token that the plant layout normally determines the design of the building, the design itself usually brings out a number of adjustments to be made in the plant layout. These adjustments are made to arrive at the most suitable end result conforming to site limitations, layout requirements, and low construction costs. In designing a new building or an addition to an existing building, the plant layout engineer, the architect, and the building-cost estimator should work closely together. Co-operation in developing the series of functional characteristics to be incorporated in the building design or the changes to be considered in the plant layout produces the reciprocal plans which will lead to the most practical and economical building design.

Variety in Building Designs

As may be observed from Figure 193, the design of factory buildings appears almost as variable as that of women's hats. In either case, no two designs seem to be the same. Whereas the form and shape of a plant are usually determined by the functional requirements of the plant layout, the style of women's hats can hardly be attributed to a correspondingly utilitarian motive.

Fundamentally, however, there are but two basic differences in plant designs, namely:

1. The ground plan of the building, and
2. The number of stories in the building.

In general, the most common ground plans, or shapes, of factory buildings follow in outline the shape of the eight capital letters, C, E, F, H, I, L, T, and U in block form, as illustrated in Figure 194. Out of these, the most prevalent, as would be expected because of its simplicity, is the letter shape I. The next four shapes followed most frequently are those of the four letters C, U, L, and E, in their order of importance.

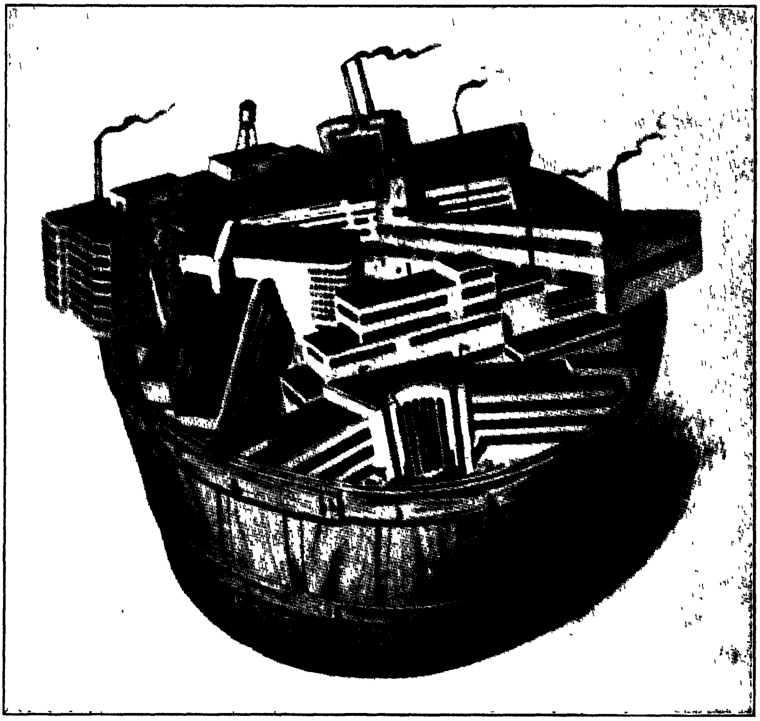


FIG. 193. *Bumper crop of building designs.* From the collection of models gathered in this bushel basket, the range of variety in building design appears almost limitless. (*Drawing through courtesy of Southern Railway System.*)

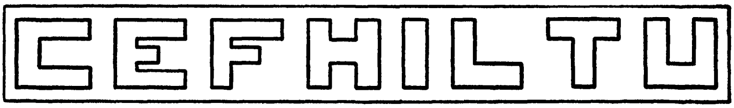


FIG. 194. The eight common letter shapes of factory buildings.

The selection of the particular building shape that will best fit the functional requirements of the layout, whether for a new building or for an extension to an existing plant, is largely made through preliminary study drawings, such as the one in Figure 191, where the letter shape U has taken form in inverted position.

An aerial view of I-, L-, and U-shaped buildings under actual construction is shown in Figure 195. In this layout, combinations of single- and multi-story buildings have been designed to accommodate the particular character of occupancy or function housed in each building.

Functional building design is now turning to such shapes as semi-circular, and even completely circular, buildings. A modern warehouse designed along these new lines has already been proposed. Another striking evidence of modern trends in building design along functional lines is the Pentagon office building in Washington, D. C.

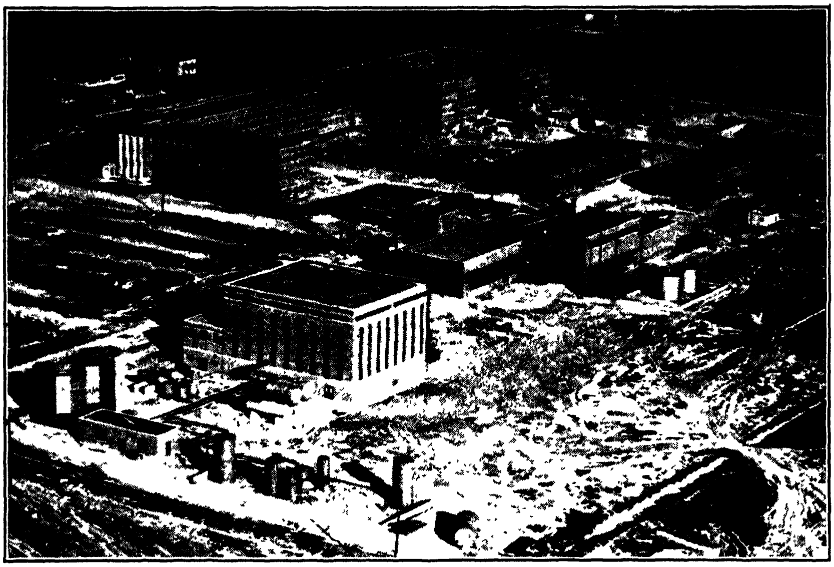
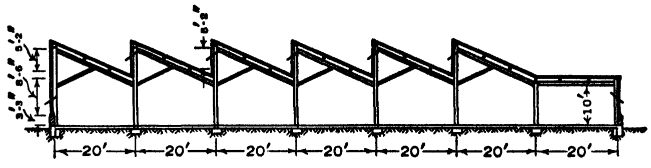


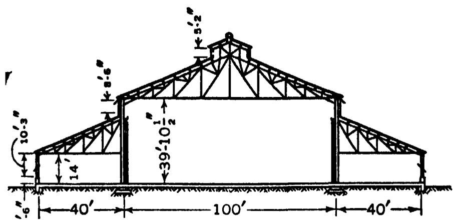
FIG. 195. *I-, L-, and U-shaped buildings under construction.* Aerial view of Research and Development Laboratory for the Sinclair Refining Company at Harvey, Ill. The large L-shaped three-story administration building can be seen on the left beyond the parking lot. It is connected to the U-shaped main laboratory building by a covered passage at the ground-floor level. Combinations of single- and multi-story buildings are used as dictated by the character of occupancy. (*Courtesy of the Austin Company, Cleveland.*)

While the shape of a factory building is primarily selected to fit the plant layout, it is also influenced by considerations of future expansion and site development. If the ground space available for the building is of generous proportions, permitting the building to be extended in any direction from its selected location on the site, future expansion of the building may be made freely in accordance with layout requirements. Where the ground space is limited or the plot boundary lines are irregular in shape, site restrictions enter into calculation. For this reason, the original location of the building on the site must allow for expansion in the direction or directions most logical to the expansion of the layout. Locating a building on a corner of the site immediately shuts off two avenues of expansion.

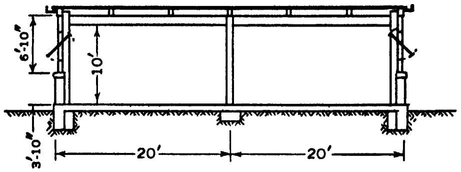
One-story industrial buildings, of whatever letter shape decided upon, may be erected along various types of elevations, depending on the sizes of bays that will best accommodate the layout and the height of overhead clearance required for operations. Considered jointly, these two factors determine the type of support for the roof, such as girders and trusses.



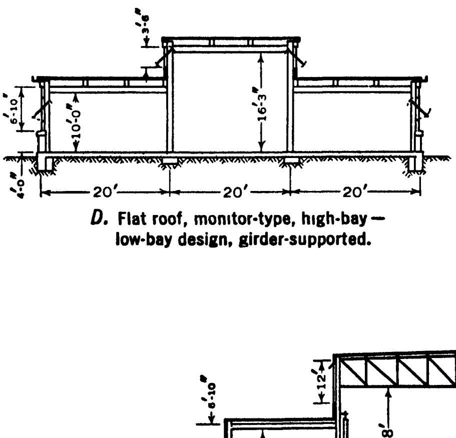
A. Sawtooth roof.



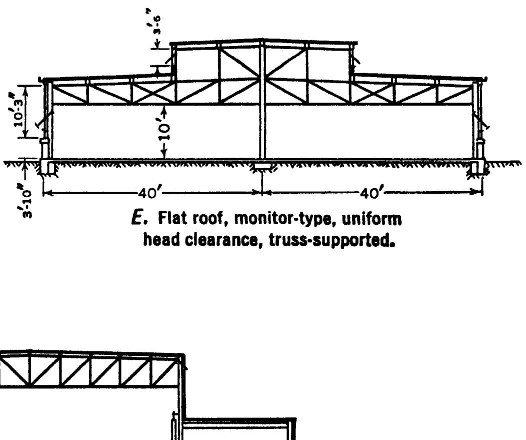
B. Pitched roof, high-bay — low-bay design.



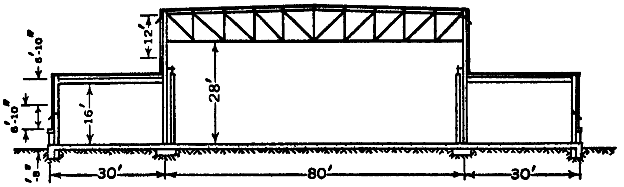
C. Flat roof, uniform clearance, girder-supported.



D. Flat roof, monitor-type, high-bay — low-bay design, girder-supported.



E. Flat roof, monitor-type, uniform head clearance, truss-supported.



F. Flat roof, monitor-type, high-bay — low-bay design, combination truss- and girder-supported.

FIG. 196. *Cross-sections* of typical one-story, steel-frame, industrial buildings.

Designs of six typical cross-sections for one-story steel-frame industrial buildings are given in Figure 196. While a number of other types are used for specific purposes, the cross-sections shown here are the ones commonly used for the average run of industrial plants. The structural standards followed in erecting these six types of buildings are outlined in Table 15.

TABLE 15. STRUCTURAL STANDARDS FOR ONE-STORY BUILDINGS

Sketch Number	Shape of Roof	Design of Bay	Roof Support	Range in Widths of Bays
A	Sawtooth	Uniform design	Direct on column	20′, 30′, and 40′
B	Pitched	High-bay: low-bay	Truss	High bays 60′, 80′, and 100′
C	Flat	Uniform design	Girder	20′, 30′, and 40′
D	Flat with Monitor	High-bay: low-bay	Girder	20′, 30′, and 40′
E	Flat with Monitor	Uniform design	Truss	40′, 50′, and 60′
F	Flat with Monitor	High-bay: low-bay	Truss and Girder	High bays 60′, 80′, and 100′

5. COLUMN SPACING AND CLEAR SPANS FOR FLEXIBLE LAYOUTS

Cost Factors Determining Column Spacing

Whether the width of a bay is to be 20, 30, 40, 50, 60, 80, or 100 feet, as indicated in the preceding section, depends principally upon the following two factors:

1. **Higher construction cost** of longer spans, and
2. **Lower operation cost** from greater flexibility in layout made possible when wide clearances of floor area are provided through wider spacing between columns.

The range of possibilities in column spacing is limited only by the net result obtained from comparing the two preceding factors. Perhaps one of the most frequent and lasting errors made in designing plant buildings is in not allowing sufficient spacing between columns. Columns become obstacles in the way of an efficient layout of machinery and equipment. Each column nullifies at least 9 square feet of floor area, and, considering the immediate surrounding space made unavailable for operations, some industrial architects conclude that this figure goes as high as 16 square feet. Naturally, the fewer the columns, the more useful is the floor area.

Long, Clear Spans

In airplane plants and locomotive manufacturing, where wide spans are necessary to permit the handling of huge-sized assembled products, engineers have avoided the proverbial forest of closely spaced columns by resorting to clear spans of 300 and 400 feet. The roof trusses in these wide-span buildings are supported on columns set on 40-foot centers running the length of the building. Specimens of these spans are shown in Figure 197 along with the traveling cranes operated in these spans.

Elimination of Columns

The day may never come when columns can be eliminated entirely, but we are living in an era when new construction material has enabled us to eliminate

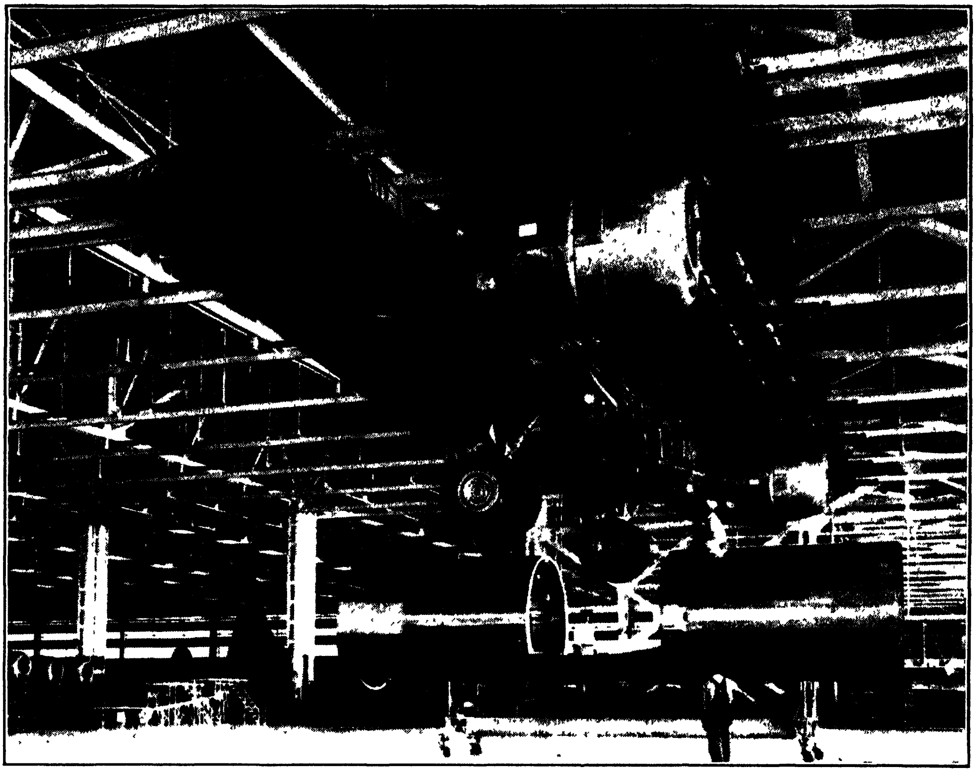


FIG. 197. *Clear span of 300 feet* in the Boeing airplane plant at Wichita, Kan. Two monorail bridge cranes, each with 10-ton lifting capacity and suspended from the roof trusses, are shown lowering the main section of a Boeing B-29 bomber, complete with inboard engine mounts and landing gear. (*Courtesy of the Austin Company, Cleveland.*)

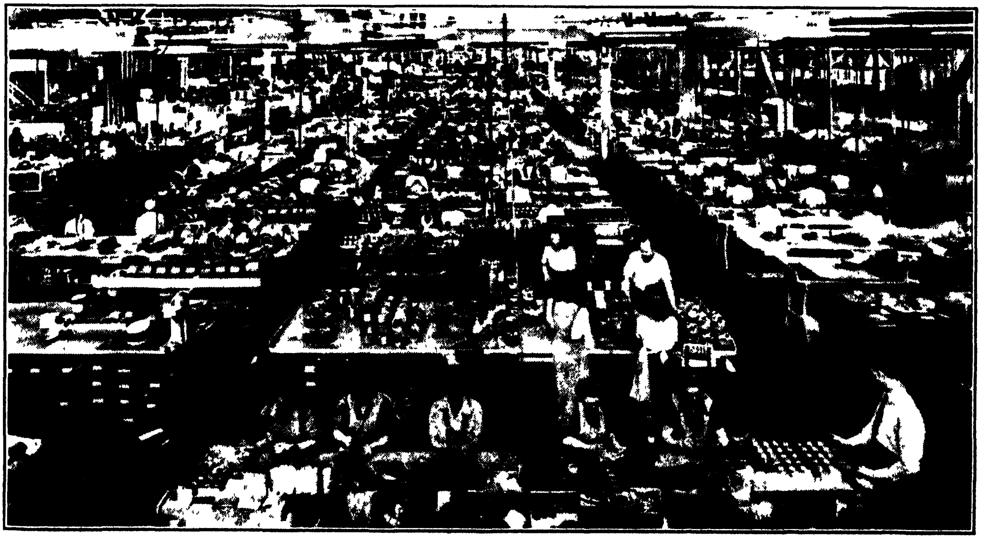


FIG. 198. *Wide, clear span in stator-winding department* of the Diehl Manufacturing Division plant of the Singer Manufacturing Company at Finderne, N. J. Conduits are dropped from the trusses to the workbenches to provide for quick and inexpensive changes in branch circuits. (*Courtesy of the Austin Company, Cleveland.*)

as much as 75 percent of the columns commonly found in the older plants where columns were placed at 20-foot intervals, both lengthwise and laterally. In many modern plants, the bays measure 20 feet by 50 feet. The present trend is to recommend column spacing of 40 feet by 80 feet. Some of the advantages gained from wide, clear spans in lightweight production are indicated in Figure 198. This photograph points out the possibilities of greater flexibility in laying out production flows and in saving floor areas otherwise sacrificed to dead spaces for columns.

The operating-cost penalty that close-column spacing imposes on operations because of a handicapped layout, and the limitations these columns place on future uses of the building, invariably more than wipe out any initial saving in construction cost when all the facts are known. It is essential, therefore, that the plant layout engineer recognize this hidden pitfall before agreeing to alter his plant layout in quest of an evasive, and perhaps largely fanciful, economy in construction cost based on close-column spacing.

CHAPTER XXI

Capital Outlays for Plant and Equipment

1. AMOUNT INVESTED IN AMERICA'S INDUSTRIAL PLANT

Comparatively Small Size of Most Enterprises

Manufacturing enterprises are rarely started on a scale exceeding 100 wage earners. It was pointed out in Chapter III that 92 percent of all the 184,230 manufacturing establishments in this country in 1939 employed not over 100 wage earners each. Many of these plants were new ventures being launched on a small scale. Others were of a nature which seldom grows larger in size. A third category consisted of marginal producers who may not have survived long enough to appear in the subsequent census.

The new enterprise usually starts by leasing space in an existing factory building or by renting a small plant. When construction activity and costs are favorable, a small plant may be built for the purpose. Whether the space is leased or owned, the new enterprise must nevertheless make capital expenditures for machinery and equipment and plan a layout for this equipment. The sum total of small ventures of yesteryear which have developed into the large manufacturing establishments of today, or which have undergone a more moderate growth, or which may have suffered in size over the years constitutes the industrial plant of this country.

Growth of America's Industrial Plant from 1915 to 1940

The total amount of capital invested in manufacturing plants and equipment in this country has never been determined factually. Rough estimates have been made, however, on the basis of Bureau of Internal Revenue statements of the asset value of corporations reporting for tax purposes. After excluding land values and adding in the assets of unincorporated businesses, the **net book value** of all manufacturing plants and equipment in this country has been estimated at the amounts shown in the accompanying table.

ESTIMATED NET BOOK VALUE OF MANUFACTURING PLANTS AND EQUIPMENT IN THE UNITED STATES

Year	Net Book Value	Percent Increase in 1940 over 1915
1915	$10,000,000,000 *	
1940	22,500,000,000 †	125%

* Estimated by L. J. Chawner in *Survey of Current Business*, March 1941, page 10.

† Estimated by J. D. Wilson, *ibid.*, November 1941, page 10.

The increase of 125% in plant and equipment in terms of dollars over the 25-year span may be considered as being also representative of the increase in physical amount of plant and equipment. It so happens that, in the two terminal years of the span, the purchasing power of the dollar, when related to wholesale prices of commodities, was at a comparable level.

Growth of America's Industrial Output from 1915 to 1940

Whether an increase of 125% over 25 years in the country's industrial plant is high or low can perhaps best be gauged by the corresponding change in the country's industrial output over that period. For the two most closely corresponding years, the output increased as follows:

INDUSTRIAL OUTPUT IN VALUE ADDED BY MANUFACTURE
FOR TOTAL UNITED STATES *

Year	Value Added by Manufacture	Percent Increase in 1939 over 1914
1914	$ 9,238,209,804	
1939	24,682,918,119	167%

* *Sixteenth Census of the United States*, 1940; Manufactures, 1939, Vol. 1, pages 17–19.

On the basis of this rough comparison, it is evident that plant and equipment assets did not keep pace with industrial output over the 25 years immediately preceding World War II. While the yearly output increased 167 percent, plant and equipment assets rose only 125 percent, or 42% less than output. This backwardness of 42% in the industrial plant amounts to $4,200,000,000 when applied to the net book value of plant assets in 1915. Thus, one year before this country became engulfed in World War II, the country's industrial plant was already lagging by $4,200,000,000 in normal growth to satisfy peacetime production requirements. The actual shortage in plants and equipment at the outbreak of World War II, however, was considerably in excess of this amount, as shown in due course in the present chapter.

Turnover of Plant Investment to Annual Output

Of particular significance in a study of plant layout and plant capacity is the relationship of the net value of plant and equipment to the value of industrial output per year. A convenient measure of this relationship for the country's industrial plant is supplied in the figures already quoted in this section. In comparing these figures, however, it is necessary to assume that the output volume for the two terminal years, 1914 and 1939, of the 25-year span, is comparable to

RELATIONSHIP OF PLANT INVESTMENT TO PLANT OUTPUT PER YEAR
FOR TOTAL UNITED STATES

PLANT INVESTMENT		ANNUAL OUTPUT		TURNOVER OF PLANT INVESTMENT TO ANNUAL OUTPUT
Net Book Value of Plant and Equipment		Value Added by Manufacture		
1915	$10,000,000,000	1914	$ 9,238,209,804	0.9
1940	22,500,000,000	1939	24,682,918,119	1.1

that of the two corresponding terminal years, 1915 and 1940, for which the plant and equipment asset figures are available.

For the country as a whole, manufacturing industries produce roughly one dollar of output (value added by manufacture) for each dollar invested in plant and equipment, as shown in the preceding table.

TABLE 16. CAPITAL OUTLAYS OVER 29 YEARS

CAPITAL EXPENDITURES FOR CONSTRUCTION AND EQUIPMENT IN THE UNITED STATES

Private and Public Capital Outlays for Industrial and Non-Industrial Activities Covering 29-Year Period 1919–1947, in Millions of Dollars of Actual Prices *

Type of New Construction and Equipment (Private and Public Combined)	Accumulated Expenditures over 29 Years	Average Expenditure per Year	Percent Distribution
Industrial construction and equipment †			
New factory buildings ‡	$ 23,730	$ 765	6%
Industrial equipment	61,518	1,985	15%
Total plant and equipment	$ 85,248	$ 2,750	21%
Non-industrial construction			
Public utilities §	$ 24,558	$ 792	6%
Commercial and institutional ‖	39,616	1,278	10%
Residential	65,102	2,100	16%
Public highways	24,931	804	6%
Farm and other construction ¶	20,970	677	5%
Total non-industrial construction	$175,177	$ 5,651	43%
Non-industrial equipment	$131,794	$ 4,251	33%
Military and naval expenditures	$ 13,378	$ 432	3%
Grand total construction and equipment	$405,597	$13,084	100%

* *Source of data:* Totals on bottom line in Table 17.

† *New construction* expenditures represent the value of work put in place over the 29 years. The data are in current dollar terms and so reflect fluctuations in cost as well as in volume. The distinction between *factory buildings* and those for *equipment* turns primarily on the mobility of the goods. Only movable goods are classified as equipment.

‡ *New factory buildings* include $7,691,000,000 for government-financed plants.

§ *Public utilities* include telegraph, telephone, gas, electric light and power, pipeline, street railway, and railroad.

‖ *Commercial and institutional* consists of warehouses, offices, lofts, stores, restaurants, garages, hotels, hospitals, and religious, educational, social, and recreational institutions.

¶ *Farm and other construction:* other construction consists of water supply, sewage disposal, public service enterprises, pipelines, and conservation and development.

2. DISTRIBUTION OF CAPITAL EXPENDITURES IN MANUFACTURING

Industrial and Non-Industrial Construction Activity

Over the 29-year period, 1919–1947, the total construction activity in this country, as summarized in Table 16, amounted to an estimated expenditure of roughly $405,597,000,000 or an average of $13,000,000,000 a year. These figures include durable equipment but leave out expenditures for work relief and maintenance. **Manufacturing plants and equipment accounted for 21 percent of total construction outlays.** Residential construction formed the next largest field (16 percent) of capital expenditures.

When new construction is separated from equipment, the following relationship shown in the table exists:

TYPE OF CONSTRUCTION ACTIVITY	ACCUMULATED EXPENDITURES OVER 29 YEARS, IN MILLIONS OF DOLLARS New Construction	 Durable Equipment	 Total Outlays
Industrial plant and equipment	$ 23,730	$ 61,518	$ 85,248
Non-industrial construction and equipment	175,177	131,794	306,971
Military and naval expenditures	13,378 *	*	13,378
Total Construction Activity	$212,285	$193,312	$405,597

*Military and naval equipment is included in new construction.

Total expenditures for new construction ($212,285,000,000) was about equal to corresponding expenditures for equipment ($193,312,000,000). Thus, by and large, as much capital is spent on durable equipment as on new construction.

Larger Investment in Machinery than in Buildings

For manufacturing industries, however, 2½ times as much is expended on equipment ($61,518,000,000) as on new factory buildings ($23,730,000,000), the ratio being 72 percent for equipment as against 28 percent for plant buildings. In constructing a new plant, therefore, it is well to keep in mind that the layout of the machinery and equipment usually represents 2½ times as much capital outlay as the cost of the building designed to house the layout.

Narrowing Differential in Lean Years

Whereas plant construction investment amounted to a weighted average of 28 percent of combined plant and equipment expenditures in the 29-year period of 1919–1947, this proportion declined to 19 percent during the decade preceding World War II.

WEIGHTED AVERAGE PERCENTAGE OF PLANT CONSTRUCTION EXPENDITURES TO COMBINED PLANT AND EQUIPMENT EXPENDITURES *

War expansion period	1915–1920	27%
Peacetime expansion	1921–1930	30%
Period of depression	1931–1940	19%
War expansion period	1941–1947	29%

* From data in columns *a*, *b*, *c*, and *d* of Table 17.

Part of the decline to 19 percent in the postwar depression decade of 1931–1940 is explained by the fact that the depression made available ample plant capacity but provided an incentive to buy more efficient machines to cut costs. There is a well-defined tendency today towards adhering to the 28 percent proportion of total investment allocated to plant construction over the 29-year period from 1919 to 1947.

3. TOTAL EXPENDITURES FOR CONSTRUCTION AND EQUIPMENT

Estimated Capital Expenditures before 1939

No **official** record exists of the amount of capital expenditures made for manufacturing plants and equipment for the country at large before 1939. The **first direct measure** of such expenditures by manufacturing concerns in the United States was provided for the year 1939 in an enumeration made by the Bureau of the Census.*

Several estimates have been made at various times by competent economists in the Federal Government, from relevant statistics available in Washington. By piecing these estimates together into a continuous pattern the 29-year trend from 1919 to 1947, shown in Table 17, was developed for all types of construction and durable equipment.

Major Swings in Capital Expenditures

The steady increase in grand total expenditures (column *m* in Table 17) experienced from 1921 to 1929 swings into a precipitous slump during the next four years. The year 1933 marks the low point in the collapse of construction activity which was felt throughout all types of plants making up the total capital goods expenditures. The decisive upturn that occurred in the following year, 1934, encountered but a minor setback in 1938 on its course to the new highs established 3 years later, in 1941, ushered in by defense activities.

4. TREND OF CAPITAL OUTLAYS FOR PLANTS AND EQUIPMENT

Gauging General Prosperity by Industrial Capital Outlays

Investment in new industrial plants and durable equipment is usually considered the key to general prosperity. Industrial investment plays this crucial role in our economy for two reasons:

1. By plowing back a fair portion of its earnings into new construction and equipment, industry is able to provide better machines and equipment to keep productivity rising.
2. When the outlook for profits darkens, capital investment is postponed, sometimes indefinitely, and thus contributes to the instability of production and employment.

The amount of earnings plowed back into new plants and equipment varies widely from year to year and from decade to decade, as plotted for the 33 years from 1915 to 1947, in Figure 199.

The trend of private and public capital outlays for industrial plants and equipment for this period is characterized by the following five successive stages:

---

* *Sixteenth Census of the United States,* 1940; Manufactures, 1939, Vol. 1, page 364.

TABLE 17. ESTIMATES OF CAPITAL EXPENDITURES FOR CONSTRUCTION AND EQUIPMENT IN THE UNITED STATES DURING THE 29 YEARS FROM 1919 THROUGH 1947

Private and Public Capital Outlays for Industrial and Non-Industrial Activities, in Millions of Dollars (1919–1947). Figures in Current Prices of the Year in Which the Expenditures Were Made

YEAR	INDUSTRIAL				NON-INDUSTRIAL						SUB-TOTAL	MILITARY	GRAND TOTAL
	Plant Construction and Equipment				Non-Industrial Construction					Non-Industrial Equipment	Total Industrial and Non-Industrial	Military and Naval Expenditures	Construction and Equipment
	New Factory Buildings		Industrial Equipment	Total Plant and Equipment	Public Utilities (Private Capital)	Commercial and Institutional	Residential (except Farms)	Public Highways	Farm and Other Construction				
	Private	Public											
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)	(m)
1915	$ 197	*	$ 419	$ 616	$ 552	$ 533	$ 950	$ 298	$ 388	$ †	$ †	$ 17	$ †
1916	262	*	790	1,052	661	716	1,066	308	422	†	†	21	†
1917	364	*	1,372	1,736	792	688	902	313	475	†	†	608	†
1918	449	*	2,017	2,466	701	521	719	288	484	†	†	1,555	†
1919	621	*	1,603	2,224	678	772	1,550	415	613	3,725	9,977	1,089	11,066
1920	1,099	*	1,991	3,090	777	1,266	1,545	640	631	4,558	12,507	161	12,668
1921	574	*	836	1,410	611	1,356	1,661	840	457	3,148	9,483	49	9,532
1922	467	*	1,123	1,590	795	1,652	2,734	851	518	2,943	11,083	25	11,108
1923	549	*	1,561	2,110	1,200	1,828	3,640	783	588	4,226	14,375	16	14,391
1924	460	*	1,320	1,780	1,366	1,931	4,195	951	665	3,804	14,692	9	14,701
1925	513	*	1,517	2,030	1,314	2,433	4,505	1,056	730	4,368	16,436	8	16,444
1926	727	*	1,693	2,420	1,441	2,754	4,496	1,039	711	4,544	17,405	11	17,416
1927	696	*	1,474	2,170	1,479	2,725	4,175	1,190	853	4,306	16,898	12	16,910
1928	802	*	1,568	2,370	1,398	2,633	3,869	1,270	814	4,625	16,979	15	16,994
1929	949	*	1,871	2,820	1,624	2,495	2,797	1,248	781	6,449	18,214	19	18,233
1930	532	*	1,438	1,970	1,568	2,190	1,446	1,481	813	4,870	14,338	29	14,367
1931	221	*	869	1,090	987	1,461	1,228	1,323	720	3,430	10,239	40	10,279
1932	74	*	516	590	482	817	462	916	475	2,090	5,832	34	5,866
1933	176	2	562	740	254	419	278	675	383	1,848	4,597	36	4,633
1934	191	11	778	980	312	509	362	821	503	2,584	6,071	47	6,118
1935	158	2	1,030	1,190	335	585	674	622	697	3,418	7,521	37	7,558
1936	266	4	1,320	1,590	454	1,039	1,192	876	854	4,368	10,373	29	10,402
1937	492	2	1,726	2,220	589	1,053	1,465	850	820	5,288	12,285	37	12,322
1938	232	12	1,186	1,430	470	1,076	1,546	837	783	4,092	10,234	62	10,296
1939	254	23	1,693	1,970	494	1,343	2,179	835	809	4,180	11,810	125	11,935

1940	442	164	2,224	2,830	580	941	2,555	875	865	5,160	13,806	385	14,191
1941	801	1,280	3,449	5,530	684	945	3,195	850	933	8,182	20,319	1,620	21,939
1942	346	3,437	5,437	9,220	687	486	1,860	675	846	7,629	21,403	5,016	26,419
1943	156	1,668	5,336	7,160	495	208	1,350	450	857	4,670	15,190	2,550	17,740
1944	208	507	3,545	4,260	648	273	725	360	515	3,789	10,570	837	11,407
1945	642	470	3,828	4,940	672	554	741	342	484	4,007	11,740	690	12,430
1946	1,689	84	4,448	6,221	856	1,896	3,570	706	901	6,424	20,574	188	20,762
1947	1,702	25	5,576	7,303	1,308	1,976	5,107	1,154	1,351	9,069	27,268	202	27,470
1919–1947	$16,039	$7,691	$61,518	$85,248	$24,558	$39,616	$65,102	$24,931	$20,970	$131,794	$392,219	$13,378	$405,597

* Public construction not segregable from private construction, 1915–1932, amount believed negligible.
† Data not available.

FOOTNOTES TO TABLE 17

Definitions

New Construction Expenditures consist of all the figures contained in columns *a*, *b*, *e*, *f*, *g*, *h*, *i*, and *l*. These figures represent the value of work put in place each year. The distinction between expenditures for *Construction*, shown in these eight columns, and those for *Equipment*, shown in columns *c* and *j*, is based primarily on the mobility of the goods. Only movable goods are classed as Equipment. The estimates of *New Factory Buildings* include such items as buildings (together with elevators, heating, plumbing, and similar accessory equipment), blast furnaces, docks, boilers, pipe, stills, tanks and vats, and similar fixed structures.

Equipment Expenditures are shown in columns *c* and *j*. This term refers, for the most part, to the movable portion of durable producers' goods, usually those having a normal useful life of 3 or more years, or as gross additions to equipment on which normal depreciation is usually accrued. Accordingly, expenditures for small tools, repairs, maintenance, and similar items are excluded.

Durable Producers' Goods is a comprehensive term including both the *New Construction* and the *Equipment Expenditures*.

Current Prices. All the data are in current dollar terms, that is, in current prices of the year in which the expenditures were made. These figures thus reflect changes in cost as well as variations in volume.

Sources

Columns a, b, e, f, g, h, i, and *l*, all on new construction expenditures. Data for 1915–1946 from *Construction and Construction Materials*, Industry Report, Statistical Supplement of May 1947, Bureau of Foreign and Domestic Commerce. Data for 1947 from advance release table of February 2, 1948, "New Construction Activity, Continental United States, 1947," joint estimate of Department of Commerce and Department of Labor.

Column c. Data obtained by deducting columns *a* and *b* from column *d*.

Column d. On total Industrial Plant and Equipment. 1915 to 1919 figures from *Survey of Current Business*, March 1941, page 11. Based on F. W. Dodge Corp. reports and other data. 1920 to 1938 figures from J. F. Dewhurst & Associates, *America's Needs and Resources*, The Twentieth Century Fund, New York, 1947, Appendix 20, pages 756–757. Data for 1939 to 1947 from advance release table of February 2, 1948, "New Construction Activity," already cited. The figures shown for Manufacturing Plant and Equipment on this table cover only expenditures of private capital. To these figures have been added the Public Industrial Outlays for factory buildings and equipment estimated by the Federal Reserve Board in the *Federal Reserve Bulletin*, September 1946, page 967, for the years 1939 to 1945. This series ended with the year 1945. For the years 1946 to 1947, a corresponding addition was made by including Public Construction of factory buildings (obtained from column *a*), plus an allowance for Public Industrial Equipment calculated at 2.7 times the Public Construction figures, which ratio prevailed in the two preceding years, 1944 and 1945.

Column j. Data obtained by deducting the aggregate of columns *d*, *e*, *f*, *g*, *h*, and *i*, from column *k*.

Column k on Total Industrial and Non-Industrial Plant and Equipment. Also known as Total Non-Military Capital Expenditures for Plant and Equipment. Data obtained by deducting column *l* from column *m*.

Column m on Grand Total Construction and Equipment. Data for 1919–1942 from Dewhurst, *op. cit.* 1943–1945 figures from advance release table cited for columns *a*, *b*, *e*, *f*, *g*, *h*, *i*, and *l*. To make the 1943–1945 series a comparable continuation of the 1919–1942 series, the Total Expenditures on New Plant and Equipment taken from the advance release table were increased to include (*a*) Agriculture, (*b*) Private Housing, (*c*) Private Institution Construction, and (*d*) Public Plant, all from *Federal Reserve Bulletin*, cited previously, and from 1946–1947 preliminary estimates.

Contents

Industrial Plant Construction and Equipment: all manufacturing industry groups classified by the U. S. Bureau of Census.

Public Utilities: telephone, telegraph, electric light and power, pipelines, street railway, and railroad.

Commercial and Institutional: warehouses, offices, lofts, stores, restaurants, garages, hotels, hospitals, and religious, educational, social, and recreational institutions.

Farm and Other Construction: other construction consists of water supply, sewage disposal, public service enterprises, pipeline, and conservation and development.

(a) 1915–1920, war expansion. Large additions to factory buildings and industrial equipment financed by private capital. Public construction of industrial plants and equipment (see Table 17, column *b*) was practically negligible, amounting to less than 1 percent of industrial outlays before 1940.

(b) 1921–1930, peacetime expansion. A sharp drop in 1921 from war expansion to peacetime level. Outlays maintained a substantial rise which reached a peak in 1929. This period was noted for broad improvements in machinery and manufacturing processes.

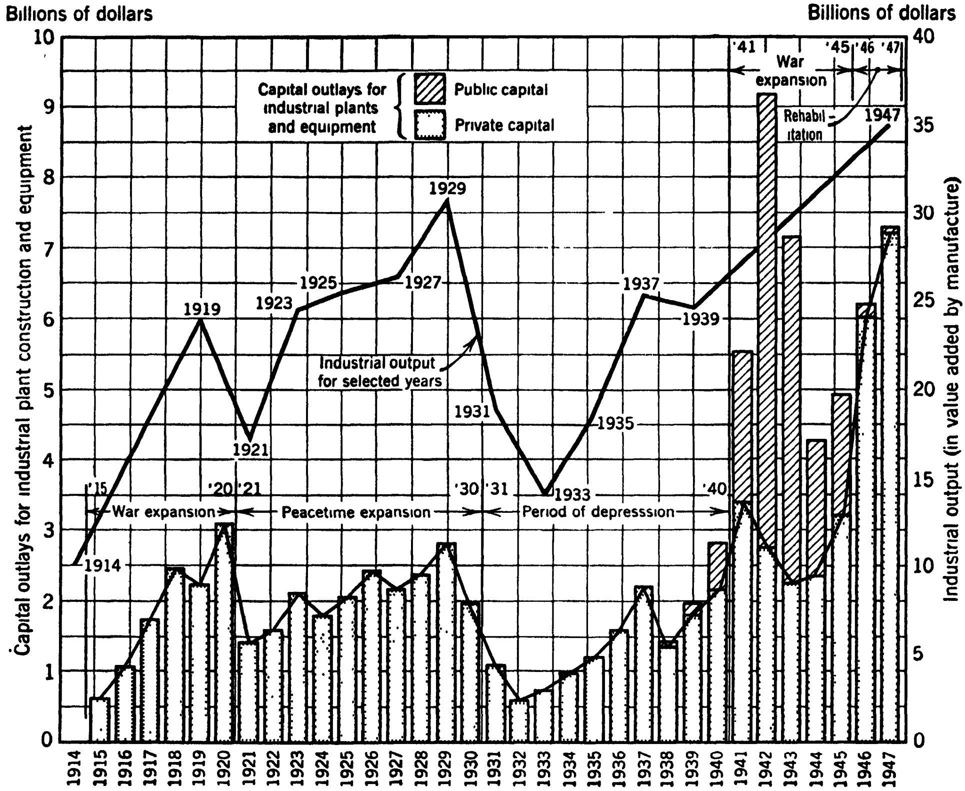


FIG. 199. *Private and public capital outlays* for industrial plants and equipment in the United States from 1915 to 1947, and industrial output for selected years. Sources of data: *Industrial output* in value added by manufacture, Sixteenth Census of the United States, 1940, and Committee for Economic Development; *public capital outlays* for industrial plants and equipment, Table 19; *private capital outlays* for industrial plants and equipment, Table 17, column (*d*), and Table 19.

(c) 1931–1940, period of depression. A sharp drop in 1931 and 1932 in industrial capital expenditures. The low figure of $590,000,000 reached in 1932 marks the bottom of the 33-year trend. Except for the year 1937, manufacturing capital expenditures for this decade remained considerably lower than in the preceding decade. However, the expenditures for plant and equipment during the depression were technically more efficient per dollar value than the expenditures in the preceding 10 years. The moderate recession in 1938 was followed by 4 years of rapid expansion, as the wheels of war production were set in motion.

(d) 1941–1945, war expansion. The year 1941 marks the advent of heavy public outlays for industrial plants and equipment, amounting to $2,100,000,000 as compared to $300,000,000 in 1940. In the 2 years following 1941, the bulk of the new facilities were built with government funds. The war facilities expansion reached its peak in 1942, when combined private and public outlays totaled $9,200,000,000. With 1942 also came the decline of private expenditures which continued through 1943. In 1944, public outlays began to give way to private capital. The facilities added during this war expansion period were provided in the most expeditious manner and at wartime inflated costs. For the most part, these additions were not designed for peacetime products.

(e) 1946–1947, post-war rehabilitation. Sharp increase in industrial expenditures to the 33-year **peak** of $7,300,000,000 in 1947, an all-time high in peacetime construction activity and surpassed only by the wartime expansion peak of $9,200,000,000 in 1942 for war facilities. The phenomenal level attained in 1946 and 1947 results from the readjustment of manufacturing facilities to meet pentup demand for civilian goods restricted during war years. This high level of capital outlays indicates also an insistant demand for new facilities required to **modernize, expand,** and **rehabilitate** existing capacity in order to serve adequately the peacetime demand for a number of years. The high costs incurred in this expansion, however, consume the dollars expended without adding a proportionate physical amount of capacity as compared to construction costs before 1940. The real gain in facilities, therefore, is considerably less than that indicated by the large amounts of dollars spent.

Shortage of Plants at Outbreak of War

During the 26 years (1915–1940) preceding World War II, the plant of American industry had been wearing out or becoming obsolete almost as fast as it was being replaced. This situation is revealed in Table 18, which summarizes capital outlays for new plants and equipment from 1915 to 1940. These expenditures were made from private sources, except for negligible amounts from government funds in 1939 and 1940.

TABLE 18. PREWAR INVESTMENT IN INDUSTRIAL PLANTS AND EQUIPMENT

Investment Activity in 26 Years, 1915–1940	Billions of Dollars
Manufacturing plant and equipment: net assets in 1915	$10.0 *
New construction of factory buildings, 1915–1940	12.0 †
Capital expenditures for industrial equipment, 1915–1940	34.5 †
Total industrial investment made in 26 years	$56.5
Less: depreciation and replacements written off in 26 years	34.0
Manufacturing plant and equipment: net assets, 1940	$22.5 *

* From section 1 in this chapter.

† From Table 17, columns *a*, *b*, and *c*.

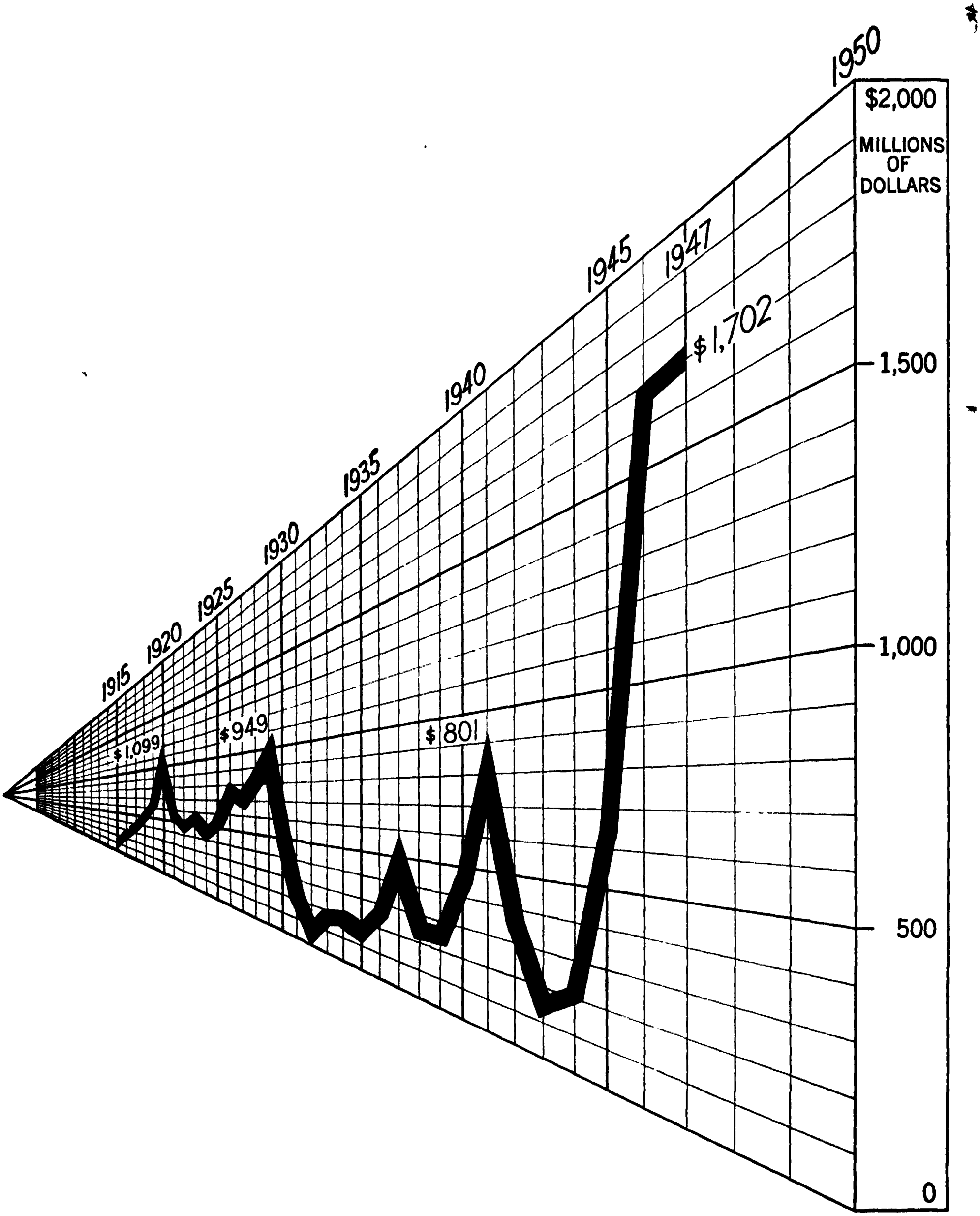


FIG. 200. *Capital outlays* for private construction of factory buildings, 1915–1947, exclusive of public construction of factory buildings and of military and naval expenditures. For supporting data, see Table 17, column (*a*).

It is evident from these figures that $34,000,000,000 were being written off while new outlays of $46,500,000,000 were being made during the 26 years preceding the war. This process left an increase of only $12,500,000,000 in net assets in 1940 over 1915. There can be no doubt that, on the eve of World War II, this country was decidedly short of industrial plants and equipment.

Following the peacetime expansion which culminated in 1929 (see Figure 199), there was very little investment in American industry until the beginning of war expansion in 1940. The 11-year period from 1929 to 1940 left a huge void below the normal-growth line connecting the year 1929 with the year 1941 on the chart in question. During this period, furthermore, plant facilities were rapidly wearing out almost as fast as they were being replaced. The negligible additions made to private plant and equipment in this country between 1929 and 1940 caught American industry with a grievous shortage in manufacturing facilities when war broke out in Europe.

Private Plant Construction at Standstill during War Expansion Period

The trend in capital outlays for the private construction of **new factory buildings,** exclusive of durable equipment, is plotted in Figure 200 for the 33-year period, 1915–1947. Before 1945 the high point was reached in 1920 without again being attained until **after** World War II in 1946, 26 years later. Except for a small rise in 1941, private plant construction was on a downward trend throughout the war expansion period.

Private outlays by manufacturers were sharply curtailed during the war by such non-war industries as paper, printing, textile, apparel, and leather. Meanwhile the high rate at which these industries operated during the war subjected the equipment to extraordinarily hard wear for which replacements were generally restricted and hence inadequate.

In contrast to the non-war industries, the war industries experienced an extensive over-all expansion in facilities financed by government funds. These industries included chemicals, petroleum products, rubber products, iron and steel, transportation equipment, machinery, and non-ferrous metals. The portion of this wartime expansion that is adaptable for peacetime use to compete with prewar facilities is a factor to be reckoned with in contemplating new plant construction. In the first 2 years of postwar rehabilitation the sharp increase in private expenditures for new factory buildings reached the 33-year peak of $1,702,000,000 in 1947, an all-time high in this type of private construction.

5. WARTIME EXPANSION ADAPTABLE FOR PEACETIME USE

Two-Thirds of Wartime Expansion Considered Adaptable

Government expenditures during World War II on plant and equipment in the manufacturing industries totaled about $17,000,000,000, as shown in Table 19. The major portion of these outlays were for plant facilities to produce aircraft, ships, ordnance, and other war materials. The Civilian Production Administration estimated that only $5,000,000,000 worth of the $17,000,000,000 of public, or federally financed, plants would have a peacetime use.*

Of the $14,000,000,000 spent by private industry for new industrial facilities during 1941–1945, however, the Federal Reserve Board (see footnotes to Table 19) estimates that practically the entire expansion can be adapted for peacetime use. The Board further estimates that, in the aggregate of public and private outlays, about $20,000,000,000 out of the total $31,000,000,000 of wartime expansion may be suitable for postwar production.

TABLE 19. WARTIME EXPANSION OF INDUSTRIAL PLANTS

Construction and Equipment During 5 Years, 1941–1945 (in Millions of Dollars)

Year	Public *	Private †	Total
1941	$ 2,130	$ 3,400	$ 5,530
1942	6,460	2,760	9,220
1943	4,910	2,250	7,160
1944	1,870	2,390	4,260
1945	1,730	3,210	4,940
5 years	$17,100	$14,010	$31,110

SOURCES:

* *Public expenditures* are mainly for industrial plants and equipment to produce war goods. Data from *Federal Reserve Bulletin*, September 1946, page 967.

† *Private expenditures* are for manufacturing plant and equipment, exclusive of mining outlays. Data from advance release table of February 2, 1948, cited in Table 17.

Total expenditures, public and private, correspond with column *d* in Table 17.

Apparent Over-Expansion in 1941–1945

The $20,000,000,000 expansion considered adaptable for peacetime use is equivalent to a yearly expansion of $4,000,000,000 over the 5 years of 1941–1945. Capital outlays made before the war averaged only $1,700,000,000 annually during 1935–1939 (see Table 17, column *d*). These figures indicate an annual over-expansion of $2,300,000,000, or 135 percent, over the 5 years of 1941–1945. That this excess wartime expansion was more apparent than real, however, is borne out by the fact that the annual expenditure for plants and equipment in the 2 years immediately following 1945 amounted to $6,200,000,000 in 1946 and $7,300,000,000 in 1947. This continually rising trend leads us to inquire briefly into the outlook for the next decade.

Large Capital Outlays Required for New Developments

A number of wartime developments of new methods, materials, and products may well increase future capital requirements for additional plants and equipment at a greater rate than accumulated demands for products. Among wartime developments which may have significant peacetime applications are: (1) new chemical products such as synthetic rubber, plastics, and synthetic fibers and fabrics; (2) new food processes and products; (3) new uses for glass, plywood,

* Civilian Production Administration, *War-created Manufacturing Plant, Federally Financed, 1940–1944*, November 15, 1945, page 5.

and the light metals; (4) high advances in aviation industry; and (5) new applications of atomic energy in power production and medicine.

To adapt these developments to civilian use will require large capital outlays for plant and equipment. New industries may grow up from some of these developments. The television industry is a recent example of an entirely new business arising in the postwar period.

CHAPTER XXII

Presenting the Proposal to the Management

1. PRELUDE TO A DECISION TO BUY NEW PLANT FACILITIES

Initial Reaction to a Proposal for Capital Outlay

Business decisions to purchase new industrial facilities, whether they are plant alterations, additions, or new construction, are influenced by a number of factors which are ultimately summed up in the level of earning power of these new facilities. While operating the existing plant, the manufacturing executive may see new plans coming across his desk every day. Unless these plans are expressed in terms of probable sales and profits involved, he may simply dispatch the plans to the proverbial pigeonhole to rest in peace.

The underlying forces which bear weight in the initial reaction to a proposal calling for capital expenditures for plant and equipment and which frequently influence the decision between a further consideration or a pigeonhole dismissal of the proposal, include the following:

1. Availability of financial resources for the outlay.
2. Amount of additional profits anticipated.
3. The competitive nature of the market.
4. Tax burden relating to the investment involved.
5. The age and utilization of the existing capacity.
6. Current level of construction costs.

Unless these forces are properly appraised and reflected in the plans, the proposal may become just another paper across the executive's desk. If, however, it contains sound indications of increased profits through lower operating cost or through an expanded sales output, it will invariably awaken interest and perhaps open the door to active consideration. Such is the acid test of most plant layout projects.

Plans for plant expansion do not necessarily always have to include increased profits in order to be thoroughly sound and attractive to management. Although the reduction of production costs stands high in the list of important reasons for new facilities, it is not always the sole criterion. Other decisive situations that at times compel management to contemplate new construction and equipment expenditures include such considerations as:

1. Essential **expansion blocked** by lack of space.
2. **Obsolescence** of existing factory buildings. This situation may require modernization of old buildings or construction of new ones to enable the enterprise to remain on a competitive level.
3. **Loss of effectiveness** of machinery and equipment caused by limitations imposed on the plant layouts by the buildings housing these layouts.
4. Need of **decentralizing operations** into smaller units to establish better control, higher efficiency, and greater flexibility for expansion.
5. Need for **changing the location** of the plant to be closer to sales markets or sources of raw materials; or for better transportation facilities; or to secure better employee facilities, such as housing, transportation, and recreation. The importance of good personnel relations in an industrial plant has become a key factor in recent years.

Each reason for plant alteration or expansion should be developed clearly and in detail. The procedures recommended for such development are contained in the preceding chapters of this book. The information gathered and evaluated in these chapters forms the basis for determining the kind and size of plant expansion best suited for the requirements at hand. These requirements have been reflected in the plant layout, and the proposal is ready for presentation to management. What this proposal should contain becomes the subject matter of the present chapter.

Motivating Factors Underlying Capital Requirements

The causal relationship of the various forces that lead to private capital expenditures for industrial plants and equipment may be summarized as follows:

1. **Market demand** and product design determine production volume and process requirements.
2. **Production volume** and process requirements determine plant layout requirements.
3. **Plant layout** requirements determine the type and size of factory buildings and the type and quantities of equipment and facilities.

Sales Approach in Final Presentation

In submitting the plant layout to management, however, the sequence of these three steps often is presented in reverse order. The building project is shown first. This is followed by the plant layout plans in the form of schematic diagrams for plant areas. To justify the proposal at this point, a summary is given of sales output, operating costs, and resulting net profit. As in most sales presentations, the price is withheld until due interest has been aroused. In the case of a plant layout project, the price is the capital outlay needed for the project. The shock of this final disclosure is frequently somewhat cushioned by the outlook for increased net profit held out to management.

2. VIEWING THE PROJECT ON A RENDERING, MODEL, OR LAYOUT

Time Required to Develop a Layout Project

Depending upon its size and scope, a plant layout project may be in preparation anywhere from less than one day up to several months, and sometimes years. The rearrangement of a work station or relocation of a productive machine takes but a portion of a day to lay out in final form. Rearrangements of whole departments and alterations or additions to existing factory buildings require several weeks or months to execute in finished stage on layout plans. After having worked for weeks or months on a layout project, the plant layout engineer is confronted with the problem of presenting it cold to a busy executive, who may be inclined to look upon it as just another item in his day's routine. It behooves the plant layout engineer, in most cases, to devise a medium for conveying at a glance the product of his weeks or months of concentration on the project.

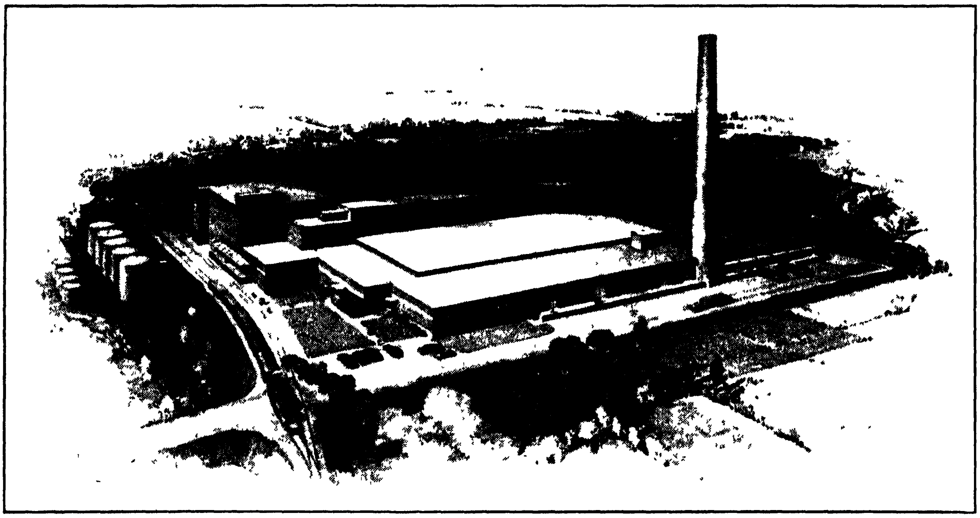


FIG. 201. *Artist's conception* portraying the finished plant in three dimensions. Rayon yarn plant of Beaunit Mills, Inc., Childersburg, Ala., is substantially one building divided into a number of sections The entire plant is windowless and fully air conditioned, not only in the process departments but also in the offices, laboratories, storage areas, and shipping space. *(Courtesy of Lockwood Greene Engineers, Inc., New York.)*

Artist's Conception

If the project covers a new plant, perhaps the most effective means of conveying to anyone what the plant will look like, how large it will be, and what its general surroundings will be like is an artist's conception portraying the finished plant in three dimensions, as illustrated in Figure 201. Pencil sketches of this type, when properly executed, are works of art fit for framing under glass.

Architect's Rendering

A close competitor of the artist's conception as an effective means of picturing a new plant is the architect's rendering, such as the one illustrated in Figure 202.

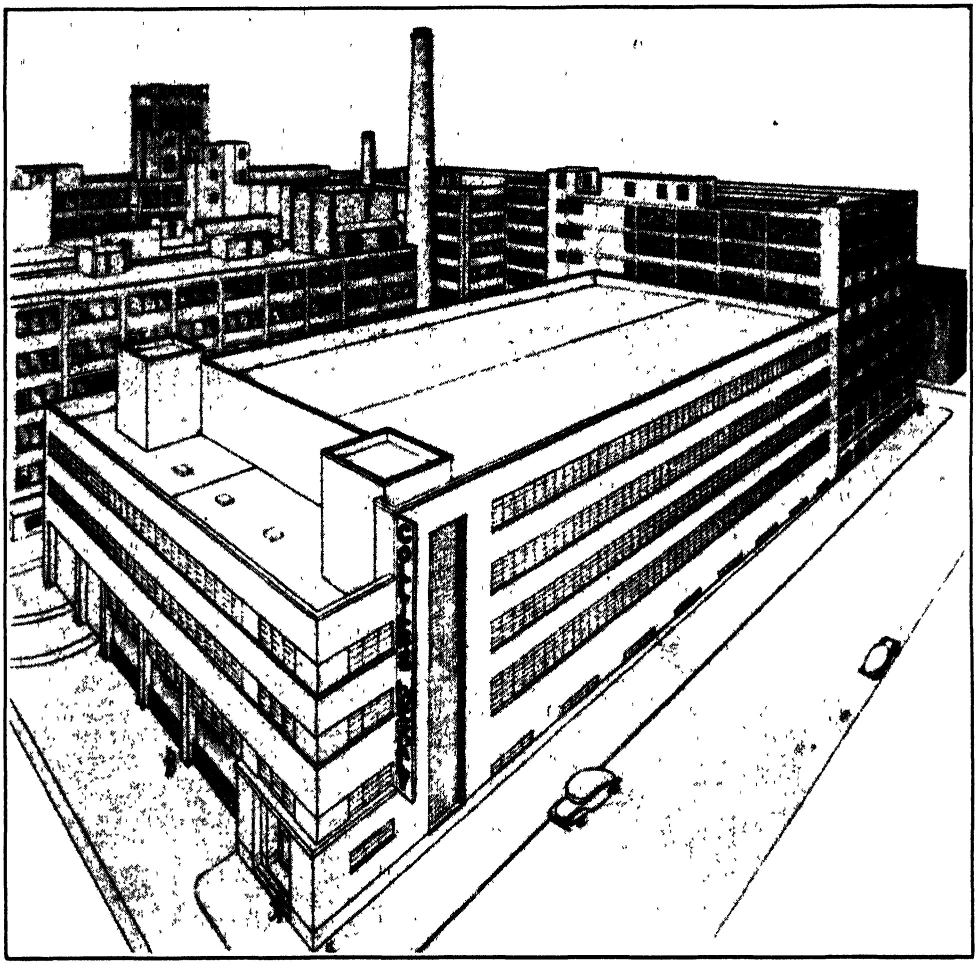


FIG. 202. *Architect's rendering of a proposed plant.* Making the plant fit the layout need not deprive the building of all architectural design. This is a multi-story building for the printing plant of the Crowell-Collier Publishing Company, Springfield, Ohio. Ordinarily a rendering is not made until the type and size of plant have been selected to suit the building requirements determined by the completed plant layout. (*Courtesy of the Austin Company, Cleveland.*)

A rendering usually follows rigid lines extended from scaled dimensions, and consequently has a somewhat cold appearance as compared to the shadowed, vanishing, and intriguing unevenness of nature contained in the artist's conception. The inevitable rigidity of the architect's rendering in Figure 202 is particularly noticeable when the rendering is compared with the photograph of the actual

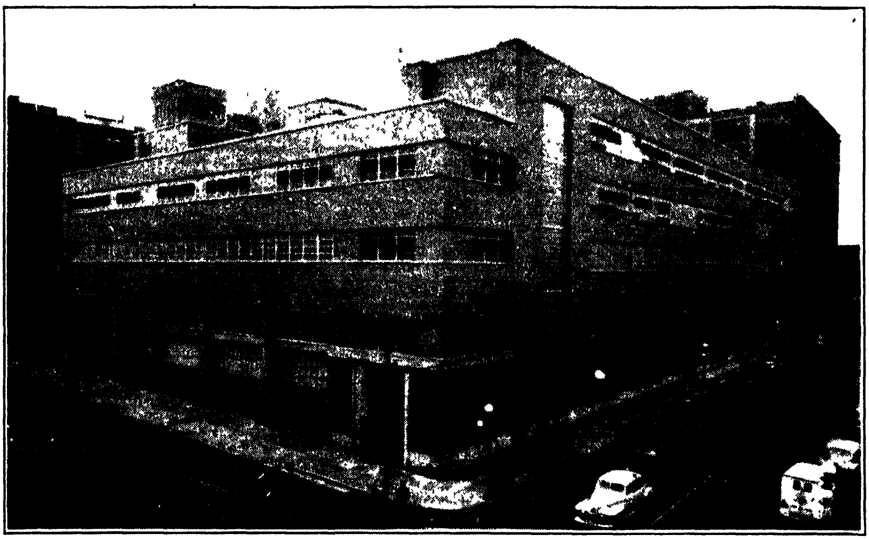


FIG. 203. *View of the completed building shown by rendering* in Figure 202. Building has been planned for the later addition of three more stories. The structure measures 146 feet (left) by 290 feet (right) and was completed in 1947 at a cost of approximately $1,500,000. (*Courtesy of the Austin Company, Cleveland.*)

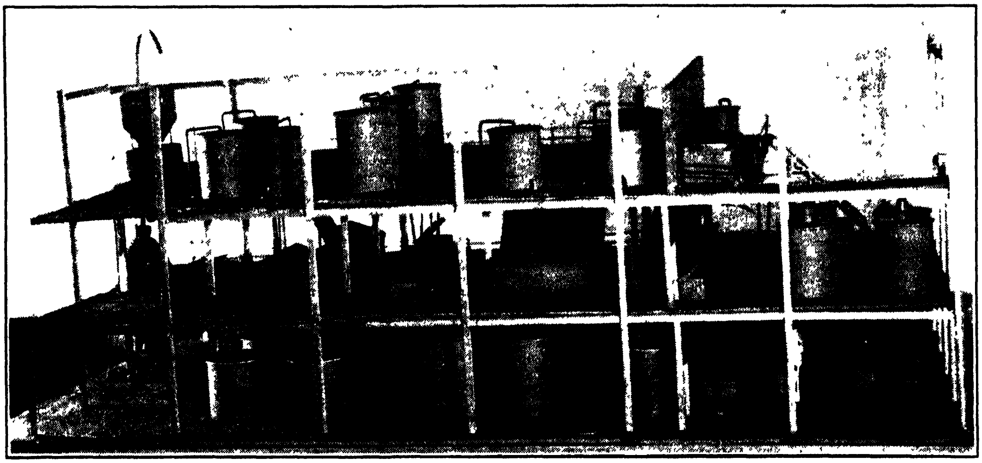


FIG. 204. *Miniature model of a multi-story plant.* Stripped of walls and roof, this scale model of a tungsten and molybdenum ore refining plant shows all units of machinery and equipment in position on each floor, and gives a realistic view of the gravity flow of work in process, from floor to floor. Columns, stairways, and production areas extending through two or more floors are clearly seen in the model. Presentations of this type convey a view of all floors at one glance, which could not be obtained from blueprints. (*Courtesy of Westinghouse Electric Corporation, Pittsburgh.*)

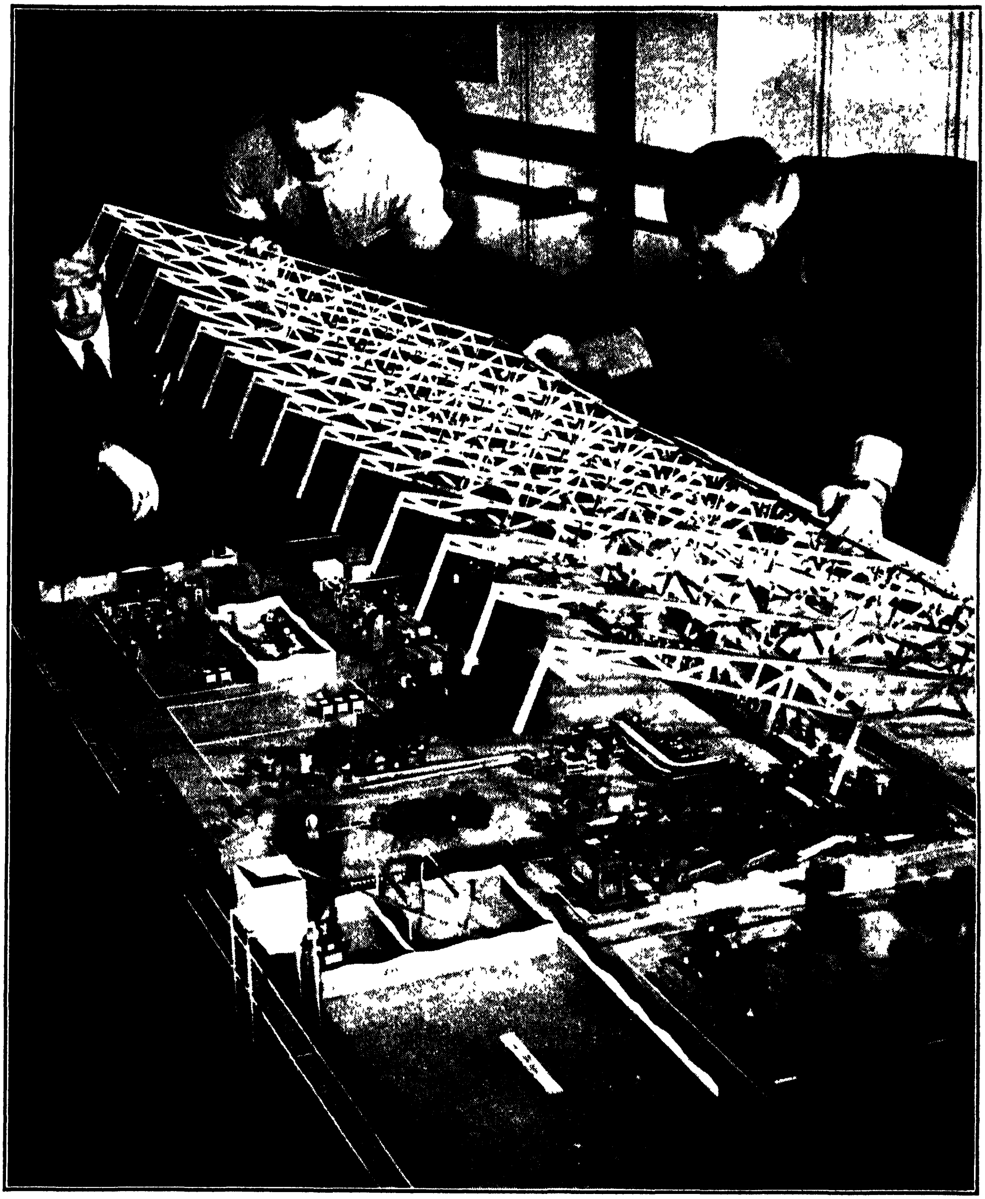


FIG. 205. *Three-dimensional layout of a single-story plant.* Removable framework of trusses and columns permits easy access to all models of machinery and equipment whenever rearrangements are desired. Note railroad siding in left foreground. For executives who have little patience or familiarity with detail layout drawings attempting to show all these units of machinery and equipment, this type of layout presentation seldom fails to arouse proper interest from the start. (*Courtesy of Gaudreau, Rimbach & Associates, Pittsburgh.*)

plant in Figure 203. The lowering of the perspective in the photograph, of course, tends to make the rendering appear somewhat exaggerated in its building lines.

Miniature Model

For less pretentious construction projects, such as alterations within existing buildings, particularly where more than one floor is involved in the plan, a miniature model of the interior of the plant, such as shown in Figure 204, has proved highly practical. What this medium lacks in artistic touch is often more than compensated for by the feeling of realism it carries regarding equipment and operations. The interrelationship of equipment established in a fully equipped miniature plant tends to lift the curtain of technical language which often conceals the fundamental merits of a project. With the aid of a pencil as an indicator, work going through complicated equipment or processing can be followed readily from one processing unit to another. This avoids beclouding the flow with technical terms not commonly understood by the various members of management who may have to pass approval on the project.

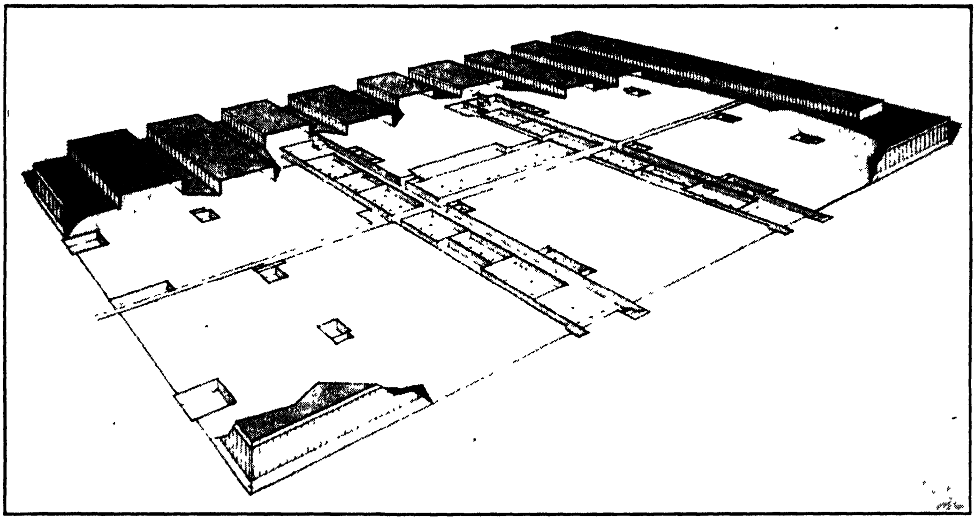


FIG. 206. *Cutaway perspective drawing.* Diagram of typical factory with roof and manufacturing floor cut away to show basement entrances, passages, and employee facilities. (*Courtesy of Albert Kahn Associated Architects and Engineers, Detroit.*)

Three-Dimensional Layout

The miniature-plant idea is equally as effective a medium of presentation when only a single floor is under consideration. When used for a single floor, the miniature model is commonly referred to as a three-dimensional layout. A specimen of this type of layout is illustrated in Figure 205.

Cutaway Perspective Drawing

A less elaborate but quickly effective method of presenting the floor areas of a single-story building is the cutaway perspective drawing illustrated in Figure 206.

The Need of a Clear Conception

Whichever form of visual aid is used, whether it be an artist's conception, an architect's rendering, a miniature model of the plant, or a more simple three-dimensional layout, the point to keep in mind is the purpose that the visual aid is to serve. The elaborateness of the medium used depends largely upon the size of the capital outlay called for in the proposal and the number of people who will have to pass on it. Some of these people may be directors, company officials, department heads, legal and accounting specialists, etc., many of whom may possess little or no knowledge of factory operations. When this is so, and it is more often than not, the proposal must be heralded by a simple, clearly understandable visual aid, if it is to be saved from the hazard of being nipped in the bud for the want of a proper conception by the approval-granting authorities.

3. ISOLATING THE PROPOSAL ON PLOT AND FLOW PLANS

Having presented a realistic conception of structural features of the proposal, the next step usually taken is to outline its functional or operational advantages. To do this clearly for a non-existent structure, or for one located at a place where some of the approval authorities are not likely to visit, again taxes the resourcefulness of the plant layout engineer.

Plot Plans

A good starting point in this attempt is to orient the reader of the proposal in the position of the project as regards the general pattern of the plant property. A plot plan showing all the existing buildings on the plant premises, such as the plan illustrated in Figure 207, serves this particular purpose in simple language which is readily understood. Shaded areas indicate the location and size of proposed building additions and extensions when the structural lines of the buildings are involved.

When no building construction is involved and only one or more internal rearrangements are considered, it is still desirable to locate these particular areas in shaded form on the plot plan. By thus providing a positive anchorage point, it is easier to form a sound conception of the proportions of the project in relation to the general scheme of manufacturing activities being carried on in the existing plant.

The most that can be expected from a plot plan in a proposal is perhaps limited to a static view of the proportion and relative location of the project. However, a three-dimensional view of the plot plan, as shown in Figure 208, provides a more realistic conception of the entire premises of the plant.

Material-Flow Diagram

The project must now be animated with a flow diagram which shows the action of the work in process as it moves through the area covered by the project. An unusually vivid illustration of the flow and processing of work in process in a

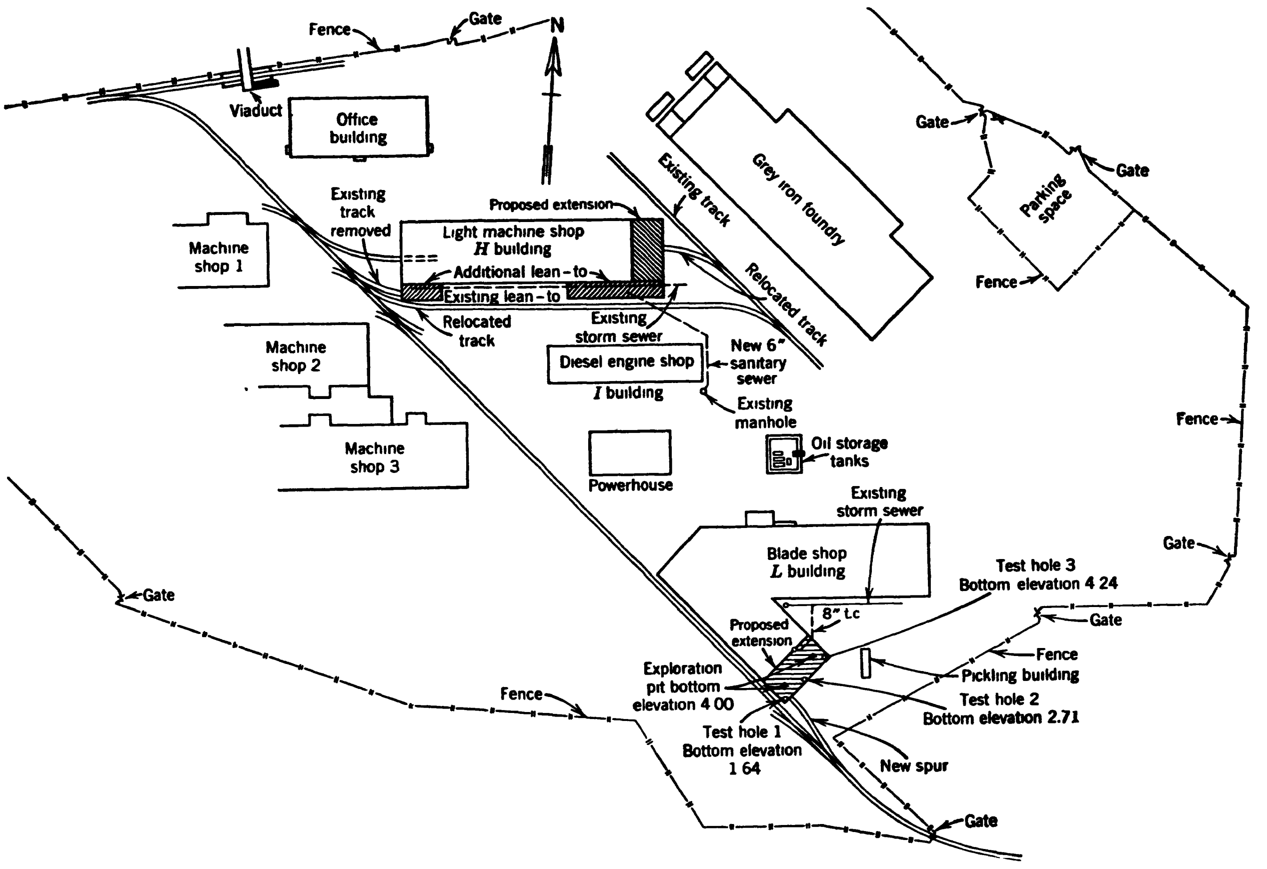


FIG. 207. *Plot plan of existing buildings* with shaded areas to indicate location and size of proposed building additions and extensions. Note the three shaded areas appended to the *H* building in the upper center and the proposed extension to the L building in the lower center. (*Courtesy of Gaudreau, Rimbach & Associates, Pittsburgh.*)

paint plant is shown in Figure 209. The entire manufacturing cycle, from incoming raw materials to outgoing finished products, is clearly depicted in this flow diagram of a paint-canning plant, even to the point of showing some of the operators in action. Although a diagram of this type is primarily intended for public consumption, it would be highly serviceable in a formal presentation, time and talent permitting.

Another schematic plan along these lines, but in much simpler form, is shown in Figure 210. This particular type, however, is prepared principally for use in submitting plant layout proposals.

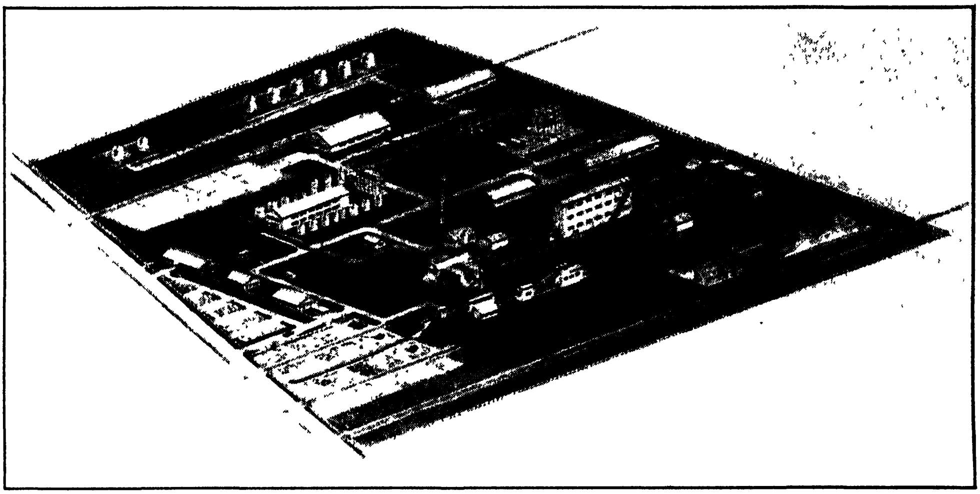


FIG. 208. *Plot plan in three dimensions* provides a realistic conception of the entire premises of the Naval Stores Plant of the Newport Industries, Inc., at Oakdale, La. (*Courtesy of Stone & Webster Engineering Corporation, Boston.*)

General Flow Plan

A more customary form of general flow plan of a plant is shown in Figure 211. The scale often used for this purpose is 1 inch per 30 feet. The course followed by the material through the plant is traced by heavy flow lines superimposed on the layout drawing showing plant departments and major activities by areas. This type of plan is first used for developing or improving flow paths to ascertain the best geographic location for each department or manufacturing activity. It is eventually incorporated into the proposal submitted to the management.

4. CASE PRESENTATION OF LAYOUT PROPOSALS FOR A FOUNDRY

Evaluation of the Proposal

Accompanying the visual aids, plans, and flow diagrams and forming perhaps the most important part of the presentation, is the evaluation of the proposal in terms of cash outlays and returns on investment. The accounting complications likely to be encountered in developing this phase of the proposal have been the

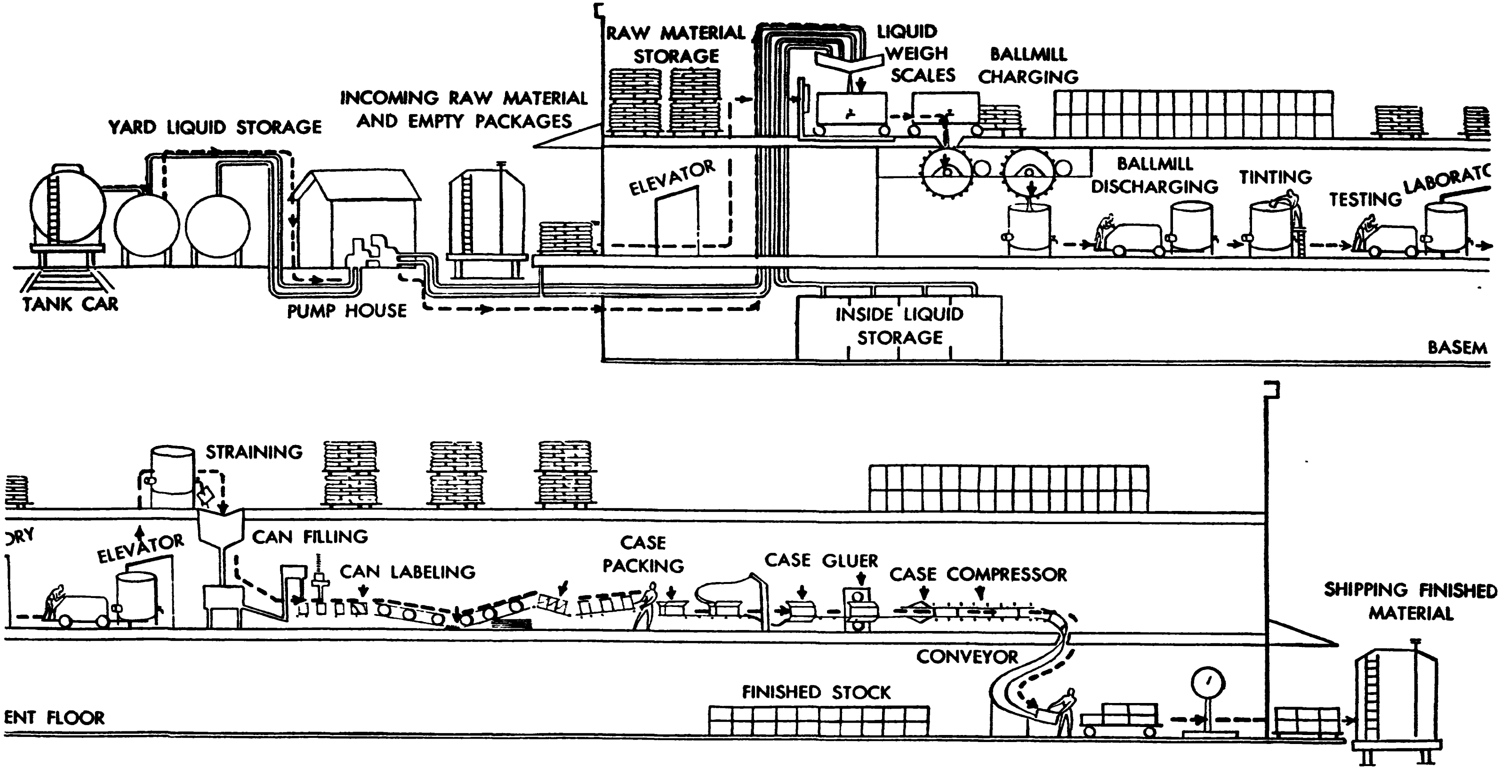


FIG. 209. *The flow of material* in a paint-canning plant, from incoming tank cars to outgoing cartons. ***Receiving and storage*** at new Springdale, Pa., paint-division plant of Pittsburgh Plate Glass Co. are speeded by up-to-date material-handling methods. Liquid ingredients are pumped from tank cars to storage. Dry raw materials like pigments and paint cans are palletized when received and unloaded from boxcars by fork truck. *First production* steps call for hauling materials by pipeline to second floor, then to 600-gallon portable tanks moved by power trucks. *Final production* jobs start when elevator lifts portable tank and truck to second-floor strainer. Conveyors are used to move paint cans past filling and labeling stations to packer. Cartons move by conveyor to machine that glues and seals them automatically. Gravity chute delivers sealed cartons to shipping department. *Shipping* department, on basement floor, assembles orders. Outgoing merchandise is moved by hand truck to covered loading dock. (*Courtesy of* Modern Industry.)

death knell of many a project, however sound it may have been from the standpoint of practical manufacturing operations.

Two principal reasons exist why many sound and practical layout projects are snuffed out of further consideration at this particular stage of the presentation. One is that plant layout engineers are normally not sufficiently familiar with accounting technique to develop the financial angles, such as sales returns, operating costs, and deductions from gross profit, of a project so as to be able to point out its true economic advantages. This function is usually placed at the mercy of a less interested individual, namely, the proverbially unexcitable accountant. The other reason is that this same accountant is seldom moved by inclination or training to wade through layout plans and supporting engineering data far enough to gain a practical insight of the basic merits of the project from an operation standpoint.

Basic Accounting Principles Involved

The fault, if such it may be called, seems to lie more heavily on the side of the engineer than on that of the accountant, however. What few basic accounting principles the engineer needs to acquire to achieve his purpose are not to be compared in magnitude with the broad technical knowledge the accountant would have to add to his own involved sphere in order to be able to analyze engineering problems intelligibly. The basic accounting principles which the engineer needs to know are illustrated in the actual presentation described below and analyzed in Section 5, which follows next.

The case presentation is that of a foundry and machine shop located in one plant. For the purpose at hand, it could be any foundry, or any other type of plant, for that matter. The layouts and accounting figures shown here for this proposal have been altered considerably to guard against the disclosure of pertinent information about this plant. The forms and method used in preparing the proposal for presentation are actual, however. The main point at issue is one of technique rather than of scrutiny of performance.

Existing and Proposed Plant Layouts

At the time the proposal was developed the plant was laid out somewhat along the lines shown in the existing layout appearing in Figure 211. Our main concern is with the existing flow of work. Using this layout as the starting point, let us examine the various rearrangements developed for it by the plant layout engineer in the modernization layout shown in Figure 212. On this plan the flow of material has been rearranged. To make this flow possible, eight separate construction projects, identified by shaded areas lettered from A to K, are considered.

Optional Investment Plans

An examination of Table 20 indicates that the eight projects, A to K, when grouped in certain ways, open up nine possibilities of modernizing this plant before considering the construction of a whole new plant. These nine possibilities are designated as investment plans, numbered from 1 to 9. Plan 1 combines proj-

TABLE 20. SUMMARY OF 10 OPTIONAL INVESTMENT PLANS FOR MODERNIZING A FOUNDRY AND MACHINE SHOP

Construction Project	DESCRIPTION OF LAYOUT PROJECTS	PLAN 1	PLAN 2	PLAN 3	PLAN 4	PLAN 5	PLAN 6	PLAN 7	PLAN 8	PLAN 9	PLAN 10
		Minimum Expenditures for Inevitable Rehabilitation	To Remove Overload from Present Large Castings	To Increase Output of Line of Extra Heavy Castings	To Add Forge Shop on Plot Between A Street and Alley	To Increase Large Castings and Add New Line at A Street	To Extend Plant across Front Street Between A and B Streets	To Add Forge Shop on Corner Plot Between C and D Streets	To Increase Large Castings and Add Forge Shop at C Street	To Extend Plant into Area 7, and Buy Section of C Street	To Build Entirely New Plant in a More Advantageous Location
A	New foundry at A Street	$398,460	$398,460	$ 398,460	$ 398,460	$ 398,460	$ 398,460	$ 398,460	$ 398,460	$ 398,460	
B	New Service building near C Street	127,175	127,175	127,175	127,175	127,175	127,175	127,175	127,175	127,175	
C	Additional 100-ton crane for heavy castings		205,100	205,100	205,100	205,100	205,100	205,100	205,100	205,100	
D	Converting 3 buildings between A and B Streets			328,360		328,360	328,360		328,360	328,360	
E	New forge shop at A Street (instead of J)				411,850	411,850	411,850				
F	Expansion area through Front Street						150,000				
J	New forge shop at C Street (instead of E)							405,250	405,250	405,250	
K	Expansion area by closing C Street									15,000	
Z	Build whole new plant in a different location										
	(a) Sell existing land, buildings, and immobile equipment, and write off unrealized net book value.										$ 937,891
	(b) Acquire land in new location, construct new buildings, and replace immobile equipment abandoned.										3,245,000 *
	(c) Loss of selling and administrative expense and of net profit for 2 months while moving to new plant location.										130,927
	Total cost of projects under each plan	$525,635	$730,735	$1,059,095	$1,142,585	$1,470,945	$1,620,945	$1,135,985	$1,464,345	$1,479,345	$4,313,818

BREAKDOWN OF INVESTMENT BY TYPES OF OUTLAYS

	PLAN 1	PLAN 2	PLAN 3	PLAN 4	PLAN 5	PLAN 6	PLAN 7	PLAN 8	PLAN 9	PLAN 10
Capital expenditure, land				$ 18,000	$ 18,000	$ 143,000	$ 32,000	$ 32,000	$ 47,000†	$ 265,000
buildings and equipment	$461,235	$662,335	$ 928,895	1,056,185	1,322,745	1,347,745	1,035,585	1,302,145	1,302,145†	2,805,000
Moving expense chargeable to manufacturing cost	64,400	68,400	130,200	68,400	130,200	130,200	68,400	130,200	130,200	175,000
Loss in net book value chargeable to reserve for depreciation										937,891
Loss of gross profit for 2 months while moving										130,927
Total cost of projects under each plan	$525,635	$730,735	$1,059,095	$1,142,585	$1,470,945	$1,620,945	$1,135,985	$1,464,345	$1,479,345	$4,313,818

* Analysis of building and equipment capital expenditure of $3,245,000 in Plan 10 appears in Table 21.

† Five-year projected returns on capital expenditures for Plan 9 are summarized in Table 22.

ects A and B. Plan 2 takes in projects A, B, and C. The remaining investment plans continue to add on or drop off the rest of the projects.

The investment expenditure starts at $525,635 for plan 1 and varies from plan to plan, attaining a modernization maximum outlay of $1,479,345 under plan 9 before considering a new plant. In the lower part of the same table is given a breakdown of each investment plan by types of outlays. That, in a nutshell, is the sum total of all the various capital outlays under consideration for modernizing the old plant. As a final alternative, a completely new plant is considered in plan 10.

Analysis of Capital Expenditure under Each Plan

For each project listed under the various investment plans in Table 20, an itemization must be made to show a separate evaluation for each constituent item. By way of illustration, an analysis is made in Table 21 of the various items of expenditure which make up the total outlay of $3,245,000 in Plan 10 to build an entirely new plant in a more advantageous location.

TABLE 21. ANALYSIS OF CAPITAL EXPENDITURE

Investment plan No.: 10 Construction project No. Z Date: May 5, 1949.

Existing property affected: Foundry and machine shop

Description of project: Acquire land, construct buildings, and replace immobile equipment in a new location

Item No.	Description of Appropriation Items	Expense	Fixed Capital
1,001	Land: 10 acres (435,600 square feet)		$265,000
1,002	Improvements underground: water, gas, electricity, compressed air, oil lines, clearing site, etc.		162,000
1,003	Factory buildings		820,000
1,004	Cranes		415,000
1,005	Furnaces and ovens		620,000
1,006	Office building		70,000
1,007	Powerhouse		81,000
1,008	Moving expense: for transferring movable assets, including new foundations for them, and transportation costs	$175,000	
1,009	Railroad switches, industrial tracks, new substation for power lines, roads, concrete floors, casting pits, storage, etc.		235,000
1,010	Pattern shop and service buildings, including storeroom, washroom, and lockers		170,000
1,011	Miscellaneous extras and unanticipated items		232,000
	Total Layout Project Z	$175,000	$3,070,000

All the plans and tables seen so far for the proposal under review are the handiwork of the plant layout engineer. The accounting phases of this presentation have not been touched upon as yet and have been reserved for consideration in Section 5.

TABLE 22. 5-YEAR ESTIMATED RETURNS ON LAYOUT PROJECTS

Investment plan No.: 9 Construction project Nos.: A, B, C, D, J, and K Date: May 5, 1949
Existing property affected: Foundry and machine shop
Description of plan: Extend plant into area 7 and buy section of C Street

DESCRIPTION OF STATEMENT ITEM	STATEMENT FOR LAST ACTUAL YEAR	ESTIMATED STATEMENT FOR NEW PLAN	RETURNS ON EXPENDITURES	
			Changes over Actual Year	Percent Change
New capital expenditure (fixed capital) for this plan			$1,349,145	
FIRST YEAR OF PLAN				
Net sales	$4,074,073	$6,043,353	+$1,969,280	+ 48
Less: cost of sales	$3,325,496	$3,962,592	+ 637,096	+ 19
deductions from gross profit	387,967	423,533	+ 35,566	
moving expense, etc., first year	---	130,200	+ 130,200	
Net profit: amount	$ 360,610	$1,527,028 *	+$1,166,418 *	
Net profit: percent	8 9	25 3	+ 16 4	
SECOND YEAR OF PLAN				
Net sales	$4,074,073	$7,053,233	+$2,979,160	+ 73
Less: cost of sales	$3,325,496	$4,128,375	+ 802,879	+ 24
deductions from gross profit	387,967	427,533	+ 39,566	
Net profit: amount	$ 360,610	$2,497,325	+$2,136,715	
Net profit: percent	8 9	35 4	+ 26.5	
THIRD YEAR OF PLAN				
Net sales	$4,074,073	$8,063,113	+$3,989,040	+ 98
Less: cost of sales	$3,325,496	$4,294,182	+$ 968,686	+ 29
deductions from gross profit	387,967	431,533	+ 43,566	
Net profit: amount	$ 360,610	$3,337,398	+$2,976,788	
Net profit: percent	8.9	41.4	+ 32 5	
FOURTH YEAR OF PLAN				
Net sales	$4,074,073	$8,663,993	+$4,589,920	+112
Less: cost of sales	$3,325,496	$4,459,991	+$1,134,495	+ 34
deductions from gross profit	387,967	435,533	+ 47,566	
Net profit: amount	$ 360,610	$3,768,469	+$3,407,859	
Net profit: percent	8 9	43.5	34.6	
FIFTH YEAR OF PLAN				
Net sales	$4,074,073	$8,855,873	+$4,781,800	+117
Less: cost of sales	$3,325,496	$4,534,161	+$1,208,665	+ 36
deductions from gross profit	387,967	439,533	+ 51,566	
Net profit: amount	$ 360,610	$3,882,179	+$3,521,569	
Net profit: percent	8.9	43.8	+ 34 9	

* First year projected returns are further analyzed in Table 23.

5. CASE DEVELOPMENT OF PROFITS ON LAYOUT PROJECTS

Analysis of the Financial Figures

Taking investment plan No. 9 for illustration, let us examine what the accountant has done with the engineer's figures described in the preceding section. Perhaps the simplest approach to an analysis of the financial figures prepared in support of the proposal is to proceed from the general to the particular. Specifically, the final accounting statement will be discussed first. From this statement, our inquiry will proceed to the more detailed data supporting it. There are four statements in all, each one dovetailing into the successive one until our perusal takes us right back into the basic estimates originally developed by the plant layout engineer.

Estimated Returns on Layout Projects

Our starting point, therefore, is the summary statement in Table 22 covering the projected profit to be derived from the plan over the first 5 years of its operation. These figures are shown in the column captioned "Estimated Statement for New Plan." All figures used throughout the present discussion are yearly amounts. This column points out that the new plan will yield an annual percentage of net profit which progresses upward over the first four years, namely, from 25.3 to 43.5 percent, and then levels off to 43.8 percent in the fifth year. In this connection, it is important to note that estimates of net profit should not stop with an examination of only the first year of operations. It may be, as in this case, that the returns in subsequent years far exceed the showing to be made in the first year.

This column by itself fails to indicate to what extent, if any, the returns from the new plan exceed the returns already being obtained from present activities. A quick glance at the column headed "Statement for Last Actual Year" shows that the existing operations are yielding but 8.9 percent in net profit and will remain at that level for the 5 years under consideration.

In the last column on the right, we find that the new plan makes it possible to increase net sales by 48 percent during the first year, accompanied by an increase of but 19 percent in cost of sales. This differential causes the percentage of net profit to jump from 8.9 to 25.3 during the first year and up to 43.8 during the fifth year.

In terms of actual money, the plan will, in its fifth year, bring in $3,521,569 more net profit per year than would be secured with the existing layout. It will be recalled from Table 20 that this plan involved a capital expenditure of $1,349,145 for land, buildings, and equipment. This investment, according to the projected net returns already indicated, would yield almost three times this amount in added net profit during the fifth year of its operation.

Analysis of Net Profit Amount

These are the figures which management needs in passing judgment on the economic soundness of a capital expenditure for new facilities. How the account-

TABLE 23. ANALYSIS OF NET PROFIT AMOUNT FOR FIRST-YEAR PROJECTED RETURNS ON CAPITAL EXPENDITURE

Investment plan No.: 9 Construction project Nos.: A, B, C, D, J and K Date: May 5, 1949
Existing property affected: Foundry and machine shop
Description of plan: Extend plant into area 7 and buy section of C Street

DESCRIPTION OF STATEMENT ITEM	STATEMENT FOR LAST ACTUAL YEAR	ESTIMATED STATEMENT FOR NEW PLAN	RETURNS ON EXPENDITURES	
			Changes over Actual Year	Percent Change
Total production in tons cast	24,700	33,200	+ 8,500	+34
Gross sales	$4,344,800	$6,574,800	+$2,230,000	+51
Less: returns and allowances	$ 136,641	$ 326,001	+$ 189,360	+14
freight outbound	134,086	205,446	+ 71,360	+53
Net sales	$4,074,073	$6,043,353	+$1,969,280	+48
Material, labor, and manufacturing expense	$3,399,195 *	$4,036,291 *	+$ 637,096	+19
Less: decrease in work in process	73,699	73,699	——	——
Cost of sales	$3,325,496	$3,962,592	+$ 637,096	+19
Gross profit	$ 748,577	$2,080,761	+$1,332,184	
Selling expenses	$ 197,142	$ 197,142	——	——
Administrative expenses	96,883	96,883	——	——
Taxes not elsewhere charged	2,686	2,686	——	——
Provision for depreciation	106,145	141,711	+$ 35,566	+33
Other income	−16,208	−16,208	——	——
Miscellaneous deductions	1,319	1,319	——	——
Total deductions from gross profit	$ 387,967	$ 423,533	+$ 35,566	
Moving expenses, etc., in first year	—	$ 130,200	+$ 130,200	
Net profit: amount	$ 360,610	$1,527,028	+$1,166,418	
Net profit: percent	8.9	25.3	+ 16.4	

Analysis of increased sales resulting from this plan

Lines of Products	Net Tons	Price per Ton	Sales Value
Extra heavy castings	6,000	$205	$1,230,000
Forged products	2,500	400	1,000,000
Total added volume	8,500		$2,230,000

---

* Statement of material, labor, and expense by cost accounts appears in Table 24.

ant arrives at such glowing results becomes our next concern. For the purpose at hand, the analysis will be confined to the figures for the first year of operations. An analysis of the net profit amount for that year is shown in Table 23. This statement is only a detail elaboration of the figures just discussed in Table 22.

In this analysis for the first year we find that the physical output in tons cast is increased by 34 percent by the new plan, but that the gross sales returns have jumped 51 percent. This spread is due to higher sales prices obtainable for the two new lines of products introduced by the new plan, as summarized at the foot of the table. The **sales price** factor, therefore, has a direct influence on the justification of the layout proposal, and the plant layout engineer should keep this in mind in developing his presentation.

With an increase of 34 percent in physical output, the amount of **returns and allowances** is increased by only 14 percent. This is another source of economic advantage for the proposal not usually included in engineers' figures of estimated manufacturing costs and resulting savings.

Another item considered on this statement is **freight outbound.** In this particular illustration, however, this element goes up 53 percent for a corresponding increase of 51 percent in gross sales and of 34 percent in physical volume. Although it happens to be unfavorable in this case, this factor must still be reckoned with. There are times when it yields a favorable differential.

Before discussing the changes in the costs of material, labor, and expense, only one group of accounts remains to be considered, namely, **deductions from gross profit.** Although the plant layout engineer seldom deals with these figures in his everyday activities, he should keep an eye on their probable effect on his proposals. In this analysis the only account affected by the new plan is **provision for depreciation.** The indicated increase of $35,566 per year for this item is accounted for by the need of depreciating the added capital expenditure necessitated by the new plan.

Material, Labor, and Expense

The analysis of material, labor, and expense shown in Table 23 is made in the statement appearing in Table 24. In this statement, we find ourselves fully in the field of the plant layout engineer's estimates. With an increase of 34 percent in tonnage produced, the statement shows that material will increase only 26 percent, direct labor 16 percent, etc. The total cost of material, labor, and expense is increased by only 19 percent for the 34 percent rise in volume.

Cost Estimates Supplied by the Plant Layout Engineer

An illustration of how the plant layout engineer arrives at his estimates is given in Table 25 for the account of direct labor encountered in the table just discussed. There we find that the amount of added cost occasioned by the increase in production is arrived at from two independent but co-ordinating angles, namely:

a. **Flat additional costs incurred by increased tonnage.** This group covers estimates of outright increases in personnel which must be made in certain

TABLE 24. STATEMENT OF MATERIAL, LABOR, AND EXPENSE

Investment plan No.: 9 **Construction projects Nos.:** A, B, C, D, J, and K **Date:** May 5, 1949
Existing property affected: Foundry and machine shop
Description of plan: Extend plant into area 7 and buy section of C Street

DESCRIPTION OF STATEMENT ITEM	STATEMENT FOR LAST ACTUAL YEAR	ESTIMATED STATEMENT FOR NEW PLAN	RETURNS ON EXPENDITURES	
			Changes over Actual Year	Percent Change
Total production in tons cast	24,700	33,200	+ 8,500	+34
Production material	$1,042,780	$1,318,352	+$275,572	+26
Direct labor	$ 838,956	$ 972,381	+$133,425 *	+16
Contributing labor	508,141	559,733	+ 51,592	+10
Supervision	187,793	187,793	——	——
Overtime premium	37,500	39,240	+ 1,740	+ 5
Clerical and maintenance labor	62,489	63,797	+ 1,308	+ 2
Vacations	55,431	61,637	+ 6,206	+11
Total labor	$1,690,310	$1,884,581	+$194,271	+11
Electric power	$ 48,590	$ 62,490	+$ 13,900	+29
Fuel	172,303	228,233	+ 55,930	+32
Chills and flasks, depreciation	52,084	72,084	+ 20,000	+38
Supplies, general	201,555	239,805	+ 38,250	+19
Repairs and maintenance supplies	108,004	135,944	+ 27,940	+26
Total power, fuel, and supplies	$ 582,536	$ 738,556	+$156,020	+27
Insurance, compensation and group	$ 36,154	$ 40,291	+ 4,137	+12
Taxes, social security	42,972	47,861	+ 4,889	+11
Taxes, property	14,059	16,266	+ 2,207	+16
Miscellaneous expenses and income	−9,616	−9,616	——	——
Total general expense	$ 83,569	$ 94,802	+$ 11,233	+13
Total material, labor, and expense	$3,399,195	$4,036,291	+$637,096	+19

* Method of estimating increase of $133,425 in direct labor is developed in Table 25.

operating and service plant departments to take care of the new projects proposed for the added business. So long as these facilities are placed in operation, they require a fixed number of attendants. This number is needed all at once and does not vary with volume, except when volume begins to exceed extreme limits.

b. **Departmental costs varying directly with increased tonnage.** These costs may be determined on a pro-rata basis per quantity unit, such as, in this case, per ton of added volume. These are the departmental costs which may be gauged statistically by one or more of the following bases:

1. Actual cost per unit.
2. Standard cost per unit.
3. Standard time value per unit.

TABLE 25. ESTIMATE OF ADDED COST FOR INCREASED PRODUCTION

Cost Account: Direct labor Plant departments: All productive and service

Investment plan No.: 9 Construction project Nos.: A, B, C, D, J, and K Date: May 5, 1949

Existing property affected: Foundry and machine shop

Description of plan: Extend plant into area 7 and buy section of C Street

PLANT DEPARTMENT	ACTUAL COST PER TON	EXTRA HEAVY CASTINGS	NEW LINE OF FORGED PRODUCTS	TOTAL ADDED COST
Increased tonnage involved		6,000	2,500	8,500
Flat additional costs incurred by increased tonnage				
Open-hearth furnaces		$ 4,000	$ 4,000	$ 8,000
Cleaning and chipping		6,000	2,000	8,000
Machine shop		25,000		25,000
Shipping labor		2,000		2,000
Maintenance labor		3,000	2,000	5,000
New forge shop			15,000	15,000
Total flat additional labor		$40,000	$23,000	$ 63,000
Departmental costs varying directly with increased tonnage				
Coremaking and molding	$6.94	41,640		41,640
Transportation (present foundry)	1.60	9,660		9,660
Machine shop	3.63		9,050	9,050
Receiving, stores, and yard	1.07		2,675	2,675
Transportation (new forge shop)	2.96		7,400	7,400
Total directly variable labor		$51,300	$19,125	$ 70,425
GRAND TOTAL ADDED COST				
Grand total additional direct labor		$91,300	$42,125	$133,425

The blueprint of management. Without delving further into accounting detail with which the plant layout engineer should be already familiar, we have come to the end of our exploration through the financial statements that usually support a proposal presented to management for consideration. The few accounting estimates encountered in our discussion are surely not beyond the grasp of the alert plant layout engineer. With these financial factors reflected in the proposal, the plant layout thus truly becomes the **blueprint of management.**

BIBLIOGRAPHY

GENERAL

Alford, L. P., *Laws of Management Applied to Manufacturing,* The Ronald Press Company, 1928.

Alford, L. P., *Principles of Industrial Management for Engineers,* The Ronald Press Company, 1940.

Alford, L. P., and Bangs, J. R. (Editors), *Production Handbook,* The Ronald Press Company, 1944.

Anderson, Arthur G., Mandeville, M. J., and Anderson, J., *Industrial Management,* The Ronald Press Company, 1942.

Anderson, E. H., and Schwenning, G. T., *The Science of Production Organization,* John Wiley & Sons, 1938.

Balderston, C. Canby, Karabasz, Victor S., and Brecht, Robert P., *Management of an Enterprise,* Prentice-Hall, 1941.

Barnes, Ralph M., and Englert, N. A., *Bibliography of Industrial Engineering and Management Literature to Jan. 1, 1943,* Wm. C. Brown Company, 1945.

Barnes, Ralph M., *Industrial Engineering and Management: Problems and Policies,* McGraw-Hill Book Company, 1931.

Barnes, Ralph M., *Motion and Time Study,* John Wiley & Sons, 1940.

Beckerath, H. von, *Modern Industrial Organization,* McGraw-Hill Book Company, 1933

Bogart, E. L., and Landon, C. E., *Modern Industry,* Longmans, Green & Company, 1936.

Buckingham, E., *Production Engineering,* John Wiley & Sons, 1942.

Bullinger, Clarence E., *Engineering Economic Analysis,* McGraw-Hill Book Company, 1942.

Cornell, William B., *Organization and Management in Industry and Business,* The Ronald Press Company, 1936.

Davis, Ralph Currier, *Industrial Organization and Management,* Harper and Brothers, 1940.

Diemer, Hugo, *Factory Organization and Administration,* McGraw-Hill Book Company, 1935.

Donald, W. J. (Editor), *Handbook of Business Administration,* McGraw-Hill Book Company, 1931.

Dutton, Henry P., *Factory Management,* The Macmillan Company, 1932.

Eidmann, Frank L., *Economic Control of Engineering and Manufacturing,* McGraw-Hill Book Company, 1931.

Griffiths, W. R. J., and Skeat, W., *Works Engineer,* Sir Isaac Pitman & Sons, 1938.

Hempel, E. H., *Top-Management Planning,* Harper and Brothers, 1945.

Holmes, Walter G., *Applied Time and Motion Study,* The Ronald Press Company, 1938.

Kimball, Dexter S., Sr., and Kimball, Dexter S., Jr., *Principles of Industrial Organization,* McGraw-Hill Book Company, 1939.

Knowles, Asa S., and Thomson, Robert D., *Industrial Management,* The Macmillan Company, 1944.

Koepke, Charles A., *Plant Production Control,* John Wiley & Sons, 1949.

Lowry, Stewart M., Maynard, Harold B., and Stegemerten, G. J., *Time and Motion Study,* McGraw-Hill Book Company, 1940.

Luzadder, Warren J., *Fundamentals of Engineering Drawing,* Prentice-Hall, 1943.

Maynard, Harold B., and Stegemerten, G. J., *Operation Analysis,* McGraw-Hill Book Company, 1939.

Shewart, W. A., *Economic Control of Manufactured Product,* D. Van Nostrand Company, 1937.

Spriegel, William R., *Industrial Management*, John Wiley & Sons, 1947.

White, Percival, *Forecasting, Planning, and Budgeting in Business Management*, McGraw-Hill Book Company, 1926.

Wilson, Frank W. (Editor), *Tool Engineers' Handbook*, American Society of Tool Engineers, McGraw-Hill Book Company, 1950.

Younger, John, and Geschelin, Joseph, *Work Routing, Scheduling, and Dispatching in Production*, The Ronald Press Company, 1936.

PLANT LAYOUT PRACTICE

Anderson, H. A., "Plant Layout as a Factor in Reducing Production Costs," *Manufacturing Record,* 114:60–61+, December, 1945.

Apple, James M., *Plant Layout and Materials Handling*, The Ronald Press Company, 1950.

Austin, W. J., "The Relation of Building and Equipment Design and Layout to Overhead Reduction," *Production Series,* No. 94, American Management Association, 1931.

Beattie, H. J., "Cost Reduction in Material Handling," *Production Series,* No. 122, pp. 26–36, American Management Association, 1940.

Beeman, D. L., "How to Plan Plant Distribution Systems," *Factory Management,* 103:145–149, September, 1945.

Berger, G. G., "25 Percent Greater Output by Better Layout," *Manufacturing Industries,* January, 1929, pages 55–57.

Bierwagen, R. W., "Redesigning a Foundry for Maximum Efficiency," *Foundry,* 72:74–78+, December, 1944.

Brady, G. S., "What the Engineer Can Do in a Small Plant: Plant Layout," *Mechanical Engineer,* 67:331–332, May, 1945.

Brown, Stanley M., "Planning and Constructing a Modern Plant," *Production Series,* No. 117, pages 61–67, American Management Association, 1939

Bullinger, C. E., *Layout of Industrial Plants,* Edwards Brothers, 1924.

Clark, H. H., "Layout Plant to Increase Output," *Manufacturing Industries,* pages 425–428, December, 1927.

Cohn, Ralph F., "Revamping Equipment and Layout," *Production Series,* No. 102, pages 13–17, American Management Association, 1936

Day, Charles, "Industrial Plants: Their Arrangement and Construction," *The Engineering Magazine,* 1911.

Devor, F. H., "How Color Helps Solve Plant Layout Problems," *Factory Management,* 102:113–116, March, 1944.

Dodge, G. W., "Planning That New Mill or Additions to Old," *Paper Industry,* 27:709–710, August, 1945.

Doud, A. T., "Developing an Industrial Plant Layout," *Industrial Management,* pages 149–152, September 1, 1921.

Dwyer, P., "Tunnels Facilitate Handling of Material in New Foundry," *Foundry,* pages 806–812, October 15, 1924.

Elstrom, A., Plant Layout, published by the author, Minneapolis, 1944.

Everson, L. E., "Plant Modernization," *Production Series,* No. 112, pages 28–34, American Management Association, 1939.

Faltus, R., and Steinmetz, C. W., *Manual of Aircraft Layout,* John Wiley & Sons, 1944.

Ferguson, H. K., 'How Can Plant Engineering Reduce Unit Costs?" *Production Series,* No. 117, pages 19–28, American Management Association, 1939.

Ferguson, H. K., "Design Your Building Around Your Handling," *Factory and Industrial Management,* pages 274–276, August, 1928.

Fibor, F. H., "Production Efficiency Raised by Operating Unity," *Food Industries,* pages 96–99, March, 1931.

Ford, T. O., "Relocation, Rearrangement, Re-equipment," *American Machinist,* pages 339–343, August 27, 1931.

Gates, P., *Workshop Operations and Layouts for Economic Engineering Production,* E. & F. N. Soon, London, 1926.

Hess, H., "Works Design as a Factor in Manufacturing Economy," *Engineering Magazine,* Vol. 27, pages 499–520, 1904.

Hiscox, W. J., *Factory Layout, Planning, and Progress,* with special reference to engineering, Sir Isaac Pitman & Sons, London, 1931.

Immer, John R., *Layout Planning Techniques,* McGraw-Hill Book Company, 1950.

Kelly, W. M., "A Shop Layout: Modern Shop Planned for Building Automatic Printing Presses," *American Machinist,* pages 281–284, February 12, 1925.

Mallick, R. W., "Three-dimensional Planning: New Trends in Industrial Plant Layout," *Mechanical Engineering.* 66:774–778, December, 1944.

Mallick, R. W., "Are Your Plant Layout and Material Handling Coordinated?" *Production Series,* No. 162, American Management Association, 1945.

Mallick, R. W., "Planning Ceramics Plants for Profit," American Ceramics Society, Conneaut Lake, September, 1948, *Ceramics Industry,* March, 1949.

Mallick, R W., "47 Percent More Output by More Efficient Plant Layout," *Steel,* 113:120, 122+, December 6, 1943.

Olsen, L. M., "Plant Layout Subject to Change," *Automotive and Aviation Industries,* 90: 34–35+, March 1, 1940.

Orcutt, H F. L., "Shop Arrangement as a Factor in Efficiency," *Engineering Magazine,* pages 717–722, January, 1901.

Patchen, R H., "Latest in Layout Did This to Costs," *Factory Management and Maintenance,* pages 47–52, February, 1934.

Richards, L E., "New Layout Means More Output with Less Effort," *Factory Management and Maintenance,* 101:89–92, December, 1943.

Rogers, T. S., "Remodeling Old Manufacturing Buildings to Cut Operating Costs," *Manufacturing Industries,* pages 135–138, February, 1928.

Sansonetti, J H., and Mallick, R. W., "Adopt the Best in Layout," *Factory Management and Maintenance,* 103:102–109, August, 1945.

Stitt, H. E., "Build the Plant to Fit the Process," *Chemical and Metallurgical Engineering,* pages 196–199, April, 1931.

Van Poppelen, F. J., "Revamping Equipment and Plant Layout," *Production Series,* No. 102, pages 4–12, American Management Association, 1936.

Wallace, H. R., "Plan Future Products for Greater Plant Efficiency," *Inland Printer,* 113:29–32, May, 1944.

Weyman, G., *Design and Arrangement of Chemical Plant in Relation to Its Economic Control,* D. Van Nostrand Company, 1925.

MANUFACTURES AND PROCESSES

Amos, P. A., *Process of Flour Manufacture,* Longmans, Green & Company, 1938.

Benedict, O., Jr., *Manual of Foundry and Pattern Shop Practice,* McGraw-Hill Book Company, 1947.

Berghell, A. B., *Production Engineering in the Aircraft Industry,* McGraw-Hill Book Company, 1944.

Bishop, J. L., *History of American Manufactures from 1608 to 1860,* 3 vols., 1866.

"Blueprint of Refinery Processes," *Oil and Gas Journal,* 43:170–216, March 31, 1945.

Blumenthal, S., *Food Manufacturing,* Chemical Publishing Company, 1942.

Camp, J. M., and Francis, C. R., *The Making, Shaping, and Treating of Steel,* Carnegie-Illinois Steel Corporation, 1941.

Clark, V. S., *History of Manufactures in the United States, 1607–1914,* 3 vols., McGraw-Hill Book Company, 1929.

Cole, A. H., *American Wool Manufacture,* Harvard University Press, 1926.

Connelly, John R., *Technique of Production Processes,* McGraw-Hill Book Company, 1943.

Dedrick, B. W., "Practical Milling," *National Miller,* 1924.

Eckman, D. P., *Principles of Industrial Process Control,* John Wiley & Sons, 1945.

Evans, Oliver, *The Young Mill-wright and Miller's Guide,* 9th Edition, 1836. First published in 1795.

Fiene, F., and Blumenthal, S., *Handbook of Food Manufacture,* Chemical Publishing Company, 1938.

"Flowsheets for Chemical Engineers," *Chemical and Metallurgical Engineering,* 1940. See also magazine issue of February, 1944, page 191, for index of additional flowsheets.

Hallock, J. W., *Production Planning,* The Ronald Press Company, 1929.

Heil, A., and Esch, W., *Manufacture of Rubber Goods,* J. B. Lippincott Company, 1928.

Horner, J. G., *Modern Iron Foundry,* Oxford, 1923.

Keir, Malcolm, *The Epic of Industry,* Vol. 5 of the *Pageant of America* series, 1926.

Laing, J., and Rolfe, R. T., *Manual of Foundry Practice,* Sherwood Press, 1934.

Leicester, S., *Practical Studies for Paper Manufacturers,* J. B. Lippincott Company, 1924.

Loring, J., and Rolfe, R. T., *Manual of Foundry Practice,* Chemical Publishing Company, 1939.

Loring, J., and Rolfe, R T., *Non-Ferrous Foundry Practice,* D. Van Nostrand Company, 1940.

Lovejoy, E., *Fundamentals and Economics in the Clay Industries,* Randall Publishing Company, 1935.

Mauersberger, H. R., and Schwarz, E. W. K., *Rayon and Staple Fibre Handbook,* Rayon Handbook Company, 1939.

McWilliam, A., and Longmuir, P., *General Foundry Practice,* Griffin, 1935.

Merrill, G. R., and others, *American Cotton Handbook,* American Cotton Handbook Company, 1941.

Miller, E. S., *Studies in Practical Milling,* Miller Publishing Company, 1941.

Modern Strip Mill, Association of Iron & Steel Engineers, 1941.

Muther, Richard, *Production Line Technique,* McGraw-Hill Book Company, 1949.

Newitt, D. M. (Editor), *Chemical Industries,* Vol. 12, Hill, 1946.

Rawson, M. N., *Little Old Mills,* E. P. Dutton & Company, 1935.

Raymond, Fairfield E., *Quality and Economy in Manufacture,* McGraw-Hill Book Company, 1931.

Rosehain, W., *Glass Manufacture,* D. Van Nostrand Company, 1928.

Scholes, S. R. (Editor), *Handbook of the Glass Industry,* Ogden-Watney, 1941

Scott, J. H., *Flour Milling Processes,* D. Van Nostrand Company, 1936.

Shreve, R. N., *Chemical Process Industries,* McGraw-Hill Book Company, 1945.

Waring, R. G., *Principles of Mill and Paint-Shop Practice,* Bruce Publishing Company, 1932.

Witham, G. S., *Modern Pulp and Paper-making,* Reinhold Publishing Corporation, 1942.

MACHINERY AND MATERIAL-HANDLING EQUIPMENT

Barker, Curtis H., Jr., and others, *Industrial Material Handling,* The Lincoln Extension Institute, Inc., Cleveland, 1950.

Brandt, A. J., and Abbott, C. J., "Effect of Proper Selection of Machines and Equipment on Setup Time," *Job Order Production Series,* No. 7, pages 2–9, American Management Association, 1933.

Chalmers, T. W., *Paper-making and Its Machinery,* D. Van Nostrand Company, 1920.

Clayton, F., "Mechanical Handling Appliances for Post-war Building," *Mechanical Handling,* 32:423–428, August, 1945.

Coes, Harold Vinton, "Preparing Production Facilities for Modern Management Methods," *Job Order Production Series,* No. 11, pages 10–17, American Management Association, 1935.

Croft, T. W., *Machinery Foundations and Erection,* McGraw-Hill Book Company, 1928.

De Groff, J. H., "Use the Most Effective Handling," *Factory Management and Maintenance,* 103:110–119, August, 1945.

Grant, E. L., *Principles of Engineering Economy,* The Ronald Press Company, 1938.

Groff, H. M., "Grouping Machines Economically," *Machinery,* April, 1924, pages 583–586.

HARDING, LOUIS ALLEN, and WILLARD, ARTHUR CUTTS, *Mechanical Equipment of Buildings*, Volume 1, John Wiley & Sons, 1929.

HUDSON, W. G., *Conveyors and Related Equipment*, John Wiley & Sons, 1949.

HUNT, W. F., *Handling Material in Factories*, Industrial Extension Institute, 1920.

Industrial Transportation Facilities, LaSalle Extension University, 1943.

JEROME, H., *Mechanization in Industry*, The Macmillan Co., 1935.

KIMBALL, D. S., "Effect of Plant Location and Machine Grouping on Profitable Operation," *Management and Administration*, pages 599–604, November, 1923.

KOSHKIN, S. J., *Modern Materials Handling*, John Wiley & Sons, 1932.

KURTZ, E. B., *Life Expectancy of Physical Property*, The Ronald Press Company, 1930.

LOCKLIN, D. PHILLIP, *Economics of Transportation* Business Publications, Inc., 1935.

MALLICK, R. W., "Material Handling—A Field for Industrial Progress," *ASME Mechanical Engineering*, June 1944, Paper 44-SA-12.

"Materials Handling: Basic Equipment for Textile Mills," *Textile World*, 95:97–102, May, 1945.

McCORMICK, J. I., "Hidden Costs in Material Handling," *ASME*, 1930, MH-52-12 Transactions.

MIEDENDORP, H., JR., "Plan Your Modernization and Replacement Program Now!" *Rayon Textile Monthly*, 25:467–472, September, 1944.

OBERG, HENRY V., "Increasing Capacity on a Production Line," *Production Series*, No. 129, pages 11–16, American Management Association, 1941.

PARKER, J. W., *Factory Transport*, Industrial Transport Publications, London, 1932.

PERRIGO, O. E., "Rearranging Machines for Greater Efficiency," *Industrial Engineer*, pages 384–389, November, 1940.

RICHARDS, EARL M., "Methods of Lowering Units Costs in the Steel Industry," *Production Series*, No. 112, page 23, American Management Association, 1939.

ROE, J. W., and LYTLE, C. W., *Factory Equipment*, International Textbook Company, 1937.

STOCKER, HARRY E., *Materials Handling*, Prentice-Hall. 1943.

TOURNIER, E. J., *Materials Handling Equipment*, McGraw-Hill Book Company, 1929.

WILLIAMSON, M. M., and G. W. (Editors), *Materials Handling Manual*, Paul Elek, Ltd., London, 1949.

WRIGHT, R. V., Materials Handling Cyclopedia, Simmons-Boardman, 1921.

PLANT SERVICE FACILITIES

Accident Facts, National Safety Council, 1939.

BLAKE, ROLAND P. (Editor), *Industrial Safety*, Prentice-Hall, 1943.

BOOMHOWER, F. K., "Engineering in Power Plant Design," *Architectural Record*, 95:92–95, May, 1944.

"Building Tomorrow's Efficiency into Today's Plants," *Power*, Special section, 88:794–824, December, 1944.

CARTMELL, M., *Stores and Materials Control*, The Ronald Press Company, 1936.

CARROLL, H. C., "Design of Small Power Plants," *Power Plant Engineering*, 49:60–65, August, 1945.

DARLINGTON, G. M., *Office Management*, The Ronald Press Company, 1935.

"Designing with Fluorescent Lighting," *Architectural Record*, 99:62–67, January, 1946.

FAIRBROTHER, F. A., "Procedure in Power Plant Design," *Architectural Record*, 95:88-91, May, 1944.

FARQUAHAR, HENRY H., *Factory Storekeeping*, McGraw-Hill Book Company, 1922.

FULLER, C. A., *Designing Heating and Ventilating Systems*, Scientific Book Corporation, 1932.

HAMPSON, D. A., "How to Lay Out the Repair Shop," *Mill and Factory*, pages 36–39, October, 1928.

Handbook of Interior Wiring Design, Industry Committee on Interior Wiring Design, 1937.

Heating, Ventilating, Air-Conditioning Guide, American Society of Heating and Ventilating Engineers, Vol. 17, 1939.

Heinrich, Herbert W., *Industrial Accident Preventions,* McGraw-Hill Book Company, 1941.

Jennings, B. H., *Air Conditioning,* International Textbook Company, 1939.

Leffingwell, W. H., *Office Management,* McGraw-Hill Book Company, 1932.

"Lighting and Air Conditioning for the Modern Plant," *Production Series,* No. 118, American Management Association, 1939.

Luckiesh, M., and Moss, Frank K., *The Science of Seeing,* D. Van Nostrand Company, 1937.

MacDonald, John H., *Office Management,* Prentice-Hall, 1937.

Mallick, R. W., "Modern Industrial Plant Layout Prevents Accidents," April, 1946, Western Pennsylvania Safety Council, ASSE

McCord, Carey P., *Industrial Accident Prevention,* McGraw-Hill Book Company, 1931.

McLachlan, N. W., *Noise,* Oxford University Press, 1935.

Mosher, H. A., "Air Conditioning versus Ventilation Systems," *Refrigerating Engineering,* 49:181–186+, March, 1945.

Pennicke, H. C., "Layout Standards for Modern Offices," *Management Review,* 34:299–301, August, 1945.

Price, George Moser, *The Modern Factory: Safety, Sanitation and Welfare,* John Wiley & Sons, 1914.

Radford, G. S., *The Control of Quality in Manufacturing,* The Ronald Press Company, 1922.

Ramsay, J., *Rest Pauses and Refreshments in Industry,* Aldwyche, London, 1939.

Recommended Practice of Industrial Lighting, Illuminating Engineering Society, 1937.

Reinhard, L. A., and Hofmeister, H., "New Trends in Office Design," *Architectural Record,* 97:99–101, March, 1945.

Simpson, B. E., "Light and Sight: First Aid for Safety and Production," *Transactions,* Illuminating Society, 1928.

"Studies for an Industrial Power Plant," *Power Plant Engineering,* 48:84–87, May, 1944.

Twyford, H. B., *Storing,* D. Van Nostrand Company, 1924

Urquhart, L. K., "How Traveling Stock Rooms Solved a Layout Problem," *Factory Management and Maintenance,* 103:88–93, April, 1945

Wallis-Tayler, A. J., *Industrial Refrigeration, Cold Storage and Ice Making,* Lockwood, London, 1929

Wylie, Harry L., Gamber, Merl P., and Brecht, Robert P., *Practical Office Management,* Prentice-Hall, 1937.

PLANT LOCATION

Carson, W. J. (Editor), *The Coming of Industry to the South,* P. S King & Son, 1930.

Davis, H. S., and others, *Vertical Integration in the Textile Industries,* University of Pennsylvania, 1938.

Garver, F. B., and others, *The Location of Manufactures in the United States,* 1899–1929, University of Minnesota Press, 1933

Hall, F. S., "The Localization of Industries," *12th Census of Manufactures,* Part I, pages cxc–ccxiv, Washington, D. C., Government Printing Office, 1900.

Holmes, W. Gerald, *Plant Location,* McGraw-Hill Book Company, 1930.

Hoover, Edgar M., *Location Theory and the Shoe and Leather Industries,* Harvard University Press, 1937.

Location of Industries, Industry and Rural Life, Ryerson Press, 1942.

McCarthy, H. H., *The Geographic Basis of American Economic Life,* Harper and Brothers, 1940.

McDonald, O. M., *Select Bibliography on Location of Industry,* McGill University, 1937.

McLaughlin, G. E., *Growth of American Manufacturing Areas,* University of Pittsburgh, 1938.

Perry, J. H., and Cuno, C. W., "Plant Location Bibliography," *Chemical and Metallurgical Engineering,* pages 121–122, May, 1941.

Smith, George C., *Industrial Surveys: an Outline for Communities and Manufacturers,* Industrial Club of St. Louis, 1930.

U. S. Bureau of the Census, *Location of Manufactures, 1899–1929,* Washington, D. C., Government Printing Office, 1933.

Urquhart, L. K., "Sylvania, a Case Study in Decentralization," *Factory Management and Maintenance,* 103:104–110, October, 1945.

Weber, Alfred, *Theory of the Location of Industries,* University of Chicago Press, 1929.

Woods, R. L., *America Reborn: A Plan for Decentralization of America,* Longmans, Green & Company, 1939.

FACTORY DESIGN AND CONSTRUCTION

Ackerman, A. J., and Locher, C. H., *Construction Planning and Plant,* McGraw-Hill Book Company, 1942.

Assessment Principles and Terminology, National Association of Assessing Officers, Chicago, 1937.

Austin, W. J., "Designing a 'Plant of Tomorrow,'" *Production Series,* No. 117, pages 29–39, American Management Association, 1939.

Barnes, F. E., *Estimating Building Costs,* McGraw-Hill Book Company, 1931.

Basic Standards of Appraisal Practice and Procedure, Association of Appraisal Executives, Washington, D. C., 1936.

Beardsley, R. C., *Design and Construction of Hydroelectric Plants,* McGraw-Hill Book Company, 1928.

Boeckh, E H., *Boeckh's Manual of Appraisals,* The Rough Notes Company, 1937.

Building: Construction, Location, Layout, Metropolitan Life Insurance Company, Group Insurance Division, 1926.

"Building in One Package: Design, Engineering and Construction: The Austin Method," *Architectural Forum,* 82:93–112, January, 1945; and 82:113–128, February, 1945.

Case, W. L., *Factory Buildings,* Industrial Extension Institute, 1928.

Dyson, S. S., and Clarkson, S. S., *Chemical Works, Their Design, Erection and Equipment,* D. Van Nostrand Company, 1912.

"Factory Design for Low-Cost Production; Building Types Study," *Architectural Record,* 98:118–140, November, 1945.

Garve, T. W., *Factory Design and Equipment, and Manufacture of Clay Wares,* Randall, 1929

Griffiths, H., *Materials of Chemical Plant Construction, Non-metals,* D. Van Nostrand Company, 1923.

Hauer, D. J., *Modern Management Applied to Construction,* McGraw-Hill Book Company, 1918.

Hermanns, H., *Planning, Erection and Operation of Modern Open-Hearth Steel Works,* D. Van Nostrand Company, 1924.

Holme, G., *Industrial Architecture,* The Studio, Ltd., London, 1935.

Huntington, W. C., *Building Construction,* John Wiley & Sons, 1941.

Jordan, J. P., "The Scrapping of Excess Plant Capacity in Industrial Readjustment," *Financial Management Series,* No. 39, 12 pages, American Management Association, 1932.

Kahn, Albert, "Building Design and Production Efficiency," *Production Series,* No. 117, pages 8–18, American Management Association, 1939.

Kahn, Inc., Albert, *Industrial and Commercial Buildings,* published by the author, Detroit, 1936.

Kent, W., *Mechanical Engineers' Handbook,* John Wiley & Sons, 1950.

Ketchum, M. S., *The Design of Steel Mill Buildings, and the Calculation of Stresses in Framed Structures,* McGraw-Hill Book Company, 1932.

Ketchum, M. S., *The Design of Walls, Bins and Grain Elevators,* McGraw-Hill Book Company, 1928.

Marks, L. S., *Mechanical Engineers' Handbook,* McGraw-Hill Book Company, 1941.

Nelson, G., *Industrial Architecture of Albert Kahn, Inc.,* Architectural Book Publishing Company, 1939.

PECK, E. C., *Modern Factory Management,* Building and Manufacturing Equipment, Lincoln Extension University, Cleveland, 1932.

PERRIGO, O. E., *Modern Machine Shop Construction, Equipment and Management,* New York, 1906.

"Pilot Plant Phases," ninth symposium on unit processes, *Industrial & Engineering Chemistry,* 37:412–450, May, 1945.

Reinforced Concrete in Factory Construction, Atlas Portland Cement Company, New York, 1919.

SOUSTER, E., *The Design of Factory and Industrial Buildings,* Scott, Greenwood & Son, London, 1919.

SWIFT, G. A., *Steel Framed Works Buildings,* Draughtsman, 1929.

TONGUE, H., *Design and Construction of High Pressure Chemical Plant,* D. Van Nostrand Company, 1930.

TYRRELL, H. G., *A Treatise on the Design and Construction of Mill Buildings and Other Industrial Plants,* Clark, Chicago, 1911.

UNDERWOOD, G., *Standard Construction Methods,* McGraw-Hill Book Company, Inc., 1931.

URQUHART, L. C., and O'ROURKE, C. E., *Design of Steel Structures,* McGraw-Hill Book Company, Inc., 1932.

VILBRANDT, F. C., *Chemical Engineering Plant Design,* McGraw-Hill Book Company, 1942.

Index

Accidents from material handling, 203, 204
Air-freight transportation, 222
Air rights for storage, 202, 231, 242
Airplane cargo, 220–222
Aisles in factory, layout of, 202–204
  location of, 25
  main traffic in, 310
  with angle storage, 236
  with inspection station, 252
Aisles in office, alignment of, 291–293
American Institute of Electrical Engineers, 204, 280
American Laundry Machinery Co., 46
American Machine and Foundry Co., 240
American Material Handling Society, 205
American Society of Mechanical Engineers, safety standards, 204
  scale-model standards, 99–101
  template standards, 98–99
American Society of Safety Engineers, 205
American Standards Association, 204, 298
American Stores Co., 40, 41
Anaconda Wire and Cable Co., 278
Architect's rendering, 225, 353
Architectural Record, 298, 299, 301
Architecture, invaded by plant layout, 25
Area diagrams, *see* Plant layout area diagrams
Artist's conception, 352, 353
Assembly line, conveyors in, 33
  double-deck system, 50
  feeding of, 200
  layout of, 32, 33
Assembly station as work center, 46, 47
Atomic age, 23
Atomic Energy Commission, 113
Atomic power plant, 113
Austin Co., The, 288, 308, 309, 311, 312, 315, 317, 318, 319, 327, 332, 335, 353, 354
Automatic Transportation Co., 237
Automation, science of, 180
Auxiliary equipment at work station, 164, 165

Beaunit Mills, Inc., 352
Bell Aircraft Corp., 318
Bin sizes, standard, 239
Bins, portable racks for, 243
  storage, 231–234, 238, 239, 241
Block templates, 94, 95
Blueprint of management, 1, 326, 370
Boeing Aircraft Co., 308, 312, 335
Boiler plants, 272–276
Boundaries of work stations, 165
Brock-Hall Dairy Co., 303
Brockway Glass Co., 220
Building design, antiquated types of, 197
  architect's rendering of, 353
  artist's conception of, 352
  bays, 333, 334
  characteristics of, 196, 201
    cross-sections, 22, 85, 333
    dimensions, 118
    drawings, 84, 85, 118
    elevations, 85, 333, 334
    functions, 325–328
    shapes, 331, 332
  functional, 332
  high-bay, 333, 334
  low-bay, 333, 334
  modern types of, 198
  one-story buildings, 333, 334
  roofs, 333, 334
  selection of, 328, 331–334, 353
  two buildings in one, 323
  variety in, 330, 331
  versus plant layout, 5
Building illustrations, antiquated plants, 197
  atomic power plant, 113
  boiler plant, 276
  ceramics plant, 36
  electronics plant, 308
  foundry and machine shop, 225
  furniture factory, 329
  hosiery mill, 163
  laboratory buildings, 332
  lamp works, 72
  linoleum plant, 327
  modern plants, 198
  naval stores plant, 359
  newspaper plant, 323
  oil refinery, 68
  ore-crushing plant, 327
  pilot plant, 58

Building illustrations, power plants, 272, 274
  printing plant, 324
  publishing plants, 353, 354
  rayon yarn plant, 352
  refractories plant, 198
  tire and rubber plant, 212
Buildings and equipment, check-list of, 68, 69
Buildings and grounds, maintenance of, 261
Bull-Dog Electric Products Co., 283
Bullard Co., The, 93

Cafeterias, layout of, 314
  seating 150 people, 313
  serving counter, 315
  serving lines, 313
  size and type of, 311–313
Canteens, 319
Capital expenditures, *see* Capital investment
Capital investment, amortization of, 191
  analysis of, 365
  benefits from layout for, 34, 35
  in construction and equipment, 322
  in plants and equipment, 337, 338, 345, 346
  influenced by production volume, 135
  plot plan for, 74
  preliminary estimates of, 60
  returns on, 366–368
  turnover of, 338, 339
  under alternate plans, 363–365
Capital outlays, *see* Capital investment
Cargo planes, 220–222
Carriers, air-freight planes, 220–221
  codes from, 215
  types of, 214, 215
Check-list, buildings and equipment, 68, 69
  data for a material-handling project, 196
  material-handling factors, 197
  production loads, 68
Chutes, classification of, 188, 189
  for cartons in glass factory, 220
Cold-cathode lighting, 289
Columns, elimination of, 334–336
  spacings of, 227
Component part analysis form, 116, 131, 142, 144
Component parts, integration of, 197
Conduits, electric, 335
Conference rooms, 292
Construction cost, *see* Capital investment
Construction expenditures, *see* Capital investment
Construction projects, 364, Fig. 212
Consulting engineers, 11
Containers, description of, 196
  physical aspects of, 199
Containers, storage of, 199
  tierable, 243
Conveyors, at work benches, 260
  classification of, 186, 187
  crossovers for, 201
  floor-mounted types of, 179, 181
  height of, 201
  in assembly line, 33
  in dispatch station, 256, 257
  overhead types of, 179, 181, 207
  plant designed along, 327
  roller, 207
  types of, 179, 181, 183
Corridors in offices, 298
Cost analysis of material handling, 196
Cost center, 172
Cost estimates by plant layout engineers, 369
Cost information for plant layout, 124, Fig. 53
Cost of labor, analyzed by accounts, 370
  decimal hours used in, 153
  direct, by departments, 371
  Labor Costimator for, 154, Fig. 69
  of material handling, 9, 180, 182, 196, 208, 209
  rates in, 153, 154
  savings from plant layout, 31, 34, 140, 144
Cost of manufacturing, analyzed by accounts, 370
  effect of work station on, 171
  estimated from plant layout, 4
  opportunity for reduction of, 10
  savings from plant layout, 34, 35, 148, 321
  why it appears high, 21
Cost of material consumption, 370
Cost of material handling, analysis of, 196
  hidden in accounting, 7, 9
  hidden in direct labor, 180
  potential savings in, 26, 27
  savings in direct labor, 180
  without sales value, 178
Cost of new construction, *see* Capital investment
Cost of product, dependence on quantity, 134, 135
  estimating of, 155
Cost of tooling, estimating of, 155
Cost records, 80
Cost reduction, *see headings beginning* Savings
Courier-Journal and Louisville Times, 295, 323
Cranes, classification of, 186, 187
  mobile types, 177
  on two levels of runways, 51
  overhead types, 177

Crossovers for conveyors, 201
Crowell-Collier Publishing Co., 353, 354
Cutaway perspective drawing, 356

Dead storage, 232
Departmental costs, 370, 371
Depression periods, 344, 345
Design, *see name of subject designed*
Desk clearances, 299, 301
Diagonal stacking, 204
Dies, design of, 193
Diesel engines, 273
Dispatch station, as a storeroom, 232
  functions of, 255, 256
  mechanization of, 257
Docks, receiving and shipping, 215–218
Doors in factory, overhead-swinging, 216
Doors in office, location and swing, 297
Douglas Aircraft Co., 317
Drafting room, 292
Drawing technique, 108–110
Drawings, cutaway perspective, 356
  for material-handling project, 201
  of buildings, 84, 85, 118
  of layout, standard data on, 110
  of machinery and equipment, 83, 86–89
  of schematic flow diagrams, 361, 362, Fig. 212
  perspective types of, 111, 112
Drinking fountains, 319
Dun & Bradstreet, Inc., 294

Electric power distribution, 277
Electrical Industrial Truck Association, 235, 236
Electricity, flow of, 273
  requirements in plants, 271, 272
Elevation of buildings, 85, 333, 334
Emerson Electric Manufacturing Co., 315
Employment office, 309, 310
Engineers, consulting, 11
Enterprises, sizes of, 337
Entrances to plants, 201
Equipment and facilities requirements form, 82, 123, 132
Equipment expenditures, *see* Capital investment
Equipment operating cost, *see* Cost of material handling
Expansion, in peacetime, 344
  in wartime, 344–348
  of enterprises, 322, 323
  of plant, plans for, 350, 351
Expenditures for plant and equipment, *see* Capital investment
Expenditures of capital, *see* Capital investment
Evans, Oliver, plant layout in 1790, 22

Factory building, *see headings beginning* Building
Factory Management and Maintenance, 93, 268, 286, 287, 328
Factory system, 23
Fairchild Aircraft Co., 222
Feeding assembly lines, 200
Field data for plant layout, 68, 69, 84–89, 117, 118, Fig. 53
Field notes, 84–86
Field sketches, 85, 87, 89
Filing cabinet clearances, 299
Financial factors in plant layout data, 125, 126, Fig. 53
Financial returns, 367
Fire extinguishers, 270
Fires, sources of, 269
Firestone Tire and Rubber Co., 272
First-aid station, 316, 317
Flat roof, 333, 334
Floor blanks, 75
Floor plans, 75, 85, 90
Floor space, 202, 229
Floor stock, 232
Flow charts, for plant layout data, 115, 120–123, Fig. 53
  of processes, *see* Process flow charts
Flow of cafeteria lines, 313
Flow of electricity, 273
Flow of material, control of, 254, 255
  core of plant layout, 211, 212
  development of, 161
  general flow plan, 359
  in a paint-canning plant, 360
  on a plant layout, 362, Fig. 212
  schematic flow diagrams, 361
  starting point of, 205
  stopping point of, 206
  through a plant, 2, 176, 177
Fluorescent lamps, 289
Forms for capacity data, actual performance on existing layout, 136
  annual saving on new layout, 140
  component part analysis, 116, 131, 142, 144
  description and purpose of, 131–133, Fig. 53
  equipment and facilities requirements, 82, 123, 132

Forms for capacity data, Labor Costimator chart, 154, Fig. 69
  machine load data, 116, 131, 132, 143
  machine-tool layout information, 81, 132
  manufacturing layout and estimate, 132, 155
  manufacturing layout data, 116, 131, 151
  material-handling activity, 206
  material-handling cost analysis, 209
  operation analysis, 120, 132
  output by types of products, 138
  plant layout comparison sheet, 132, 148
  product load analysis, 131, 141, 144
  standard time operation routing, 130
  template sheet, 91
  work sheet for operation and process flow charts, 161
  work station layout, 119, 132, 166
Forms for cost data, analysis of capital expenditures, 365
  description and purpose of, 124, 126, Fig. 53, 359, 363, 365, 367, 369–371
  estimated added cost for increased production, 371
  estimated returns on layout projects, 366
  material, labor, and expense, 370
  optional investment plans, 364
  optional profit plans, 125, 126, Fig. 53
  projected returns on capital expenditures, 368
Functional building design, 332
Functional production line, arrangement, 51, 55
  description, 43

Gaudreau, Rimbach and Associates, 6, 7, 23, 32, 33, 44, 76, 77, 81, 82, 95, 104, 106, 107, 154, 159, 221, 266, 355, 358, 361
Gauge rooms, modernization of, 249–251
General Electric Co., 51, 235, 236, 308, 314, 320
General Motors Corp., 50, 92, 316, 319
General offices, 295, 296, 302
Germicidal lamps, 320
Goodyear Tire and Rubber Co., 212
Gravity tanks, 269, 270

Handicraft industries, 23
Handlings, number of, 176
Harbison-Walker Refractories Co., 197, 198
Hauling to storage, 200
Hauserman, E. F., Co., 297, 300, 302
Hazards from traffic, 201
Heat balance, 272
Hoists, classification of, 188, 189
Household industries, 23
Humboldt Full Fashioned Hosiery Mills, 162, 163, 313

Illuminating Engineering Society, 288
Illumination levels, 287, 288
Incandescent lamps, 289
Indexed time values, 170
Industrial engineering, advent of, 23
Industrial lamps, 289
Industrial management, 23
Industrial output, 338, 344
Industrial revolution, 23
In-plant feeding, 311
Inspection department layout, 246–249
Inspection of material, 215
Inspection station, in production line, 252
  location, 253
International Business Machines Corp., 293
Inventory controls, 230
Inventory levels, 146
Inventory taking, 237
Investment, *see* Capital investment

Job-lot orders, 145
Job lots, stages in development of, 39

Kahn, Albert, Associated Architects and Engineers, 50, 74, 207, 216, 260, 292, 310, 356
Kellex Corp., 113
Kellogg, M. W., Co., 58, 70, 71, 113
Key plans, 75, 77
Kitchen layout, 314–316
Kitchen mobile unit, 312

Labor cost, *see* Cost of labor
Labor Costimator chart, 154, Fig. 69
Labor group, 172
Labor productivity, 31
Laboratories, layout of, 304
  modernization of, 249–251
Lady Esther, 260
Lamps, types of, 289
Landscaping, 307
Lane Co., The, 329
Lavatories, 319, 320
Laydowns of templates, 90, 92, 103
Layout, *see* Plant layout
Lift trucks, types of, 192
Lifts, classification of, 188, 189
Lighting, cafeteria, 315
  cold-cathode, 289
  general, 288
  measurement of, 287, 288
  medical department, 318
  objectives of, 286, 287

Lighting, of offices, 291–294, 305, 306
  requirements, 286–289
  types of lamps for, 289
  types of systems of, 288
Line storage, 232, 251
Lineshafts, 24, 284–286
Lipe-Rollway Corp., 175
Load-center distribution, 281
Loading facilities, 218, 220, 221
Lockers for employees, 319, 320
Lockwood Greene Engineers, Inc., 162, 163, 274, 275, 295, 313, 315, 323, 327, 352

Machine clearances, 256, 257
Machine crew as work center, 45, 46, 48
Machine load, calculations, 152
  data forms, 116, 131–132, 143
Machine operation, detail data, 149, 150
  estimates, 150–152
  mechanization, 182
  sequence, 193
Machine-tool layout information form, 81, 132
Machinery and equipment, drawings of, 83, 86–89
  field sketches of, 86–88
  layout data on, 82–84
  maintenance of, 261
  operation factors of, 157
  record cards of, 80–83
  selection of, 156
  spotting on layout, 88, 89
  templates of, 90, 91
Machinery and tooling, selection of, 152
Mail department, 294
Maintenance, buildings and grounds, 261
  machinery and equipment, 261
  service departments, 261
  tools, 266
Maintenance activities, 261
Maintenance department, centralization of, 259, 260
  classification of, 260
  decentralization of, 260
  location of, 259, 260
  size of, 261, 262
Maintenance work categories, 261
Management, blueprint of, 1, 326, 370
  industrial, 23
Manufacturing cost, *see* Cost of manufacturing
Manufacturing cycle reduced by layout, 34
Manufacturing expense, *see* Cost of manufacturing
Manufacturing layout and estimate form, 132, 155
Manufacturing layout data form, 116, 131, 151
Manufacturing methods, analysis, 150–152
  operation factors, 157
  selection, 154–156, 168
  work motions, 170, 171
Manufacturing stages of growth, 39, 42
Market research, 133
Market survey, 4
Marketing aspects, of plant layout, 66, 67, 116, Fig. 53
  profit determination of, 125, 126
  sales forecast of, 144, 145
Marketing cost, 66
Mass production, description of, 42, 43
  in baking industry, 40, 41
  in small-motor plant, 52–54
Material, description of, 196
  flow diagram of, 357–359
  handling of, 226, 227
  inspection of, 215
  physical aspects of, 199
  quality control factors of, 245, 246
  shortage of, 235
  value of handling of, 230
Material cost, *see* Cost of material
Material handling, activity of, 205
  basic data for project of, 196
  check-list of factors of, 197
  cost of, *see* Cost of material handling
  definition of, 176
  flow diagram for, *see* Flow of material
  mileage traveled in plant, 178
  number of, 176
  savings in, *see* Cost of material handling
  time for, 178, 180
  tons handled per ton shipped, 177, 178
  weight of material received, 211
Material-handling applications, in assembly line, 47, 50
  in baking industry, 40, 41
  in canning factory, 360
  in ceramics plant, 260
  in chip disposal by conveyors, 207
  in foundry and machine shop, 362
  in gear-motor plant, 32, 33
  in hosiery mill, 162
  in loading cargo planes, 222
  in small-motor plant, 52, 54
  in turbine plant, 51
  in work station, 44, 47, 166, 171–175, 240

Material-handling equipment, classification of, 185–189
  design of, 182
  double-deck assembly system, 50
  pallets of work in process, 235, 236
  racks for unit loads, 129, 241
  study drawing of handling system, 328
  types of conveyors, 179, 181, 183
    cranes, 177, 185
    lift trucks, 192
    skids, 192
    tiering machines, 192
    tractor-and-trailer trains, 190
  unit loads in a glass factory, 220
Material-handling operations, by machine operators, 191
  damage in, 251
  dispatch stations, 255–257
  operating factors of, 157
  inspection stations, 253
  outdoor storage area, 237
  prepositioning of material, 240
  project data, 196
  receiving-inspection department, 248
  reduction in, 193
  relation to plant layout, 195
  signs of improper layout, 37
  starting and stopping points of, 196, 205, 206
  storage at work stations, 173, 174
  volume of operations, 196
  work in process, 235
Mechanization, *see* Plant modernization
Medical department, 316–318
Medical services, types of, 316
Mercury-vapor lamps, 289
Methods engineering, concepts of, 167
  layout data from, 10
Methods studies, of principal operations, 167, 168
  technique of, 169
Mileage traveled by material, 178
Miniature plants, atomic power plant, 113
  electronic plant, 308
  foundry molding and casting, 112
  furniture factory, 329, 330
  metalworking plant, 355
  naval stores plant, 359
  oil refining plant, 354, 356
  scale models used in, 112, 113, 330, 356
Modern Industry, 360
Modernization of plants, *see* Plant modernization
Monitor roof, 333, 334
Monorail systems, bridge cranes for, 335
  classification of, 188, 189
  vertical curves in, 201
Motion economy, sweep of hands, 45
Motor drives, *see* Power drives
Motor vehicle data, 217

National Safety Council, 204, 298
Naugatuck Chemical Co., 274, 275
Net profit amount, 367, 369
New developments, 348, 349
Newport Industries, Inc., 359

Office, areas, 293, 294
  clearances and dimensions, 296, 297
  departmental boundaries, 49
  facilities, 303
  layout information, 291–294
  lighting, 291–294, 305, 306
  location, 290
  planning, 290, 291
Office design, drafting room, 292
  employment office, 309
  general offices, 291, 306
  mail department, 294
  president's office, 295
  private offices, 301, 305
  tabulating room, 293
  types of offices, 291, 292, 294–296
Operating cost, *see* Cost of manufacturing
Operation analysis form, 120, 132
Operation factors, analysis of, 157
Operation routing, 130
Operation sequence, 120
Operation volume in material handling, 196
Orders, manufacturing, 145
Outdoor storage, 237
Outlays of capital, *see* Capital investment
Output capacity, of production center, 173
  of work station, 173
Output per plant in U. S., 56, 57

Pallets, placement of, on floors, 203, 204
  in warehouses, 200
Parking lots, 307
Partitions in offices, at angles, 297
  off center, 300
Pedestrian traffic, 310
Perspective drawings, additions to a plant, 325
  architect's rendering, 352
  artist's conception, 352
  cutaway drawing, 356

Perspective drawings, foundry and factory, 224
  rolling mill for aluminum foil, 111, 112
Philadelphia Electric Co., 277, 289
Pilot plant, 58
Pilot run, 169
Pitched roof, 333, 334
Pittsburgh Plate Glass Co., 360
Plant, atomic power, 113
Plant approach, 309
Plant building, *see headings beginning* Building
Plant capacity versus market demand, 67
Plant departmental boundaries, 48, 49
Plant departments, actual performance in, 136, 137
  description of, 172
  types of, 49
  work centers in, 48
Plant entrance for employees, 308
Plant expansion, increase in production, 9, 38
  in foundry and factory, 224, 225
  in foundry and machine shop, 358
  in miniature, 330
  in oil refinery, 70, 71
  in wartime, 348
  plans for, 350, 351
  stages of growth of, 39
Plant investment, *see* Capital investment
Plant layout, advantages of good design, 27, 31, 34, 35
  in 1790, 22
  scope of project, 57, 58
  signs of improper layout, 20, 35–37
  subdivisions of, 172
Plant layout area diagrams, allocations on, 122
  of electric-motor plant, 78
  of machinery and assembly plant, Fig. 55
  schematic flow diagram, 361
Plant layout boards, in a frame, 93
  mural, 92
Plant layout capacity, 136–139
Plant layout comparison sheet form, 132, 148
Plant layout data, categories of, 115, Fig. 53
  cost information, 124, 126, Fig. 53, 359, 363, 367, 369–371
  field data, 68, 69, 84–89, 117, 118, Fig. 53
  flow charts, 115, 120–123, Fig. 53
  intangible factors in, 4, 66, 67, 116, Fig. 53
  of machinery and equipment, 82–84
  on existing facilities, 68, 69
  on operating details, 149, 150
Plant layout data, on production, 68, 116, 117, Fig. 53
  on production facilities, 80–84, 118–120, Fig. 53
  on template laydowns, 123, Fig. 53
Plant layout design, accuracy of calculations for, 149
  antiquated plants, 29
  cross-sections of one-story buildings, 333
  cutaway perspective drawing, 356
  estimating machine operations, 150–152
  general principles of, 325–328, 330–333
  long-range planning, 329
  modern plants, 30
  ore-refining plant, 354
  pilot plant for, 58
  preliminary steps in, 147
  schematic flow diagram, 212, 361, 362
  shuffling machine templates, 164
  study drawing from, 328
  study plans, 304
  technical knowledge of processes, 149
  three-dimensional, 355, 359
  time values for, 152, 153
  work-station layouts, 44, 165, 166
Plant layout development, by methods engineering, 10
  with scale models, 105–108, 112, 355
Plant layout engineer, duties of, 16, 17
  personal characteristics, 14–16
  technical qualifications, 16, 17
Plant layout engineering, definition of, 2
  development of, 2
  espousal by time study, 24
  functions of, 1
  fundamental concepts of, 1, 28
  objectives of, 37, 38, 114
Plant layout flow charts, 115, 120–123, Fig. 53
Plant layout organization, company-wide department, 11
  departmental group, 13
  functional chart of, 12
  functions of personnel in, 18
  under plant engineer, 11
Plant layout plan specimens, additions to a plant, 325
  administration and chemistry building, 304
  architect's rendering of plant, 353
  artist's conception of plant, 352
  automobile factory, 92
  cafeteria, 314
  cross-section of power plant, 275
  cutaway perspective drawing, 356
  fluorescent ballast department, 96

Plant layout plan specimens, foundry and factory, 224
  foundry and machine shop, 362, Fig. 212
  gear-motor plant, 32, 33
  gristmill in 1790, 22
  hosiery mill, 162
  lamp works, 73
  machining and assembly plant, Fig. 55
  molding plant, 213
  office layouts, 300, 302, 303
  oil refinery, 69
  perspective drawings, 111, 112, 224, 325, 352, 353, 356
  plot plans, 73, 74, 76, 77, 308, 358, 359
  receiving and inspection department, 248
  rolling mill for aluminum foil, 111, 112
  scale-model plans, 102–107, 112, 355
  schematic flow diagram, 361
  study drawing from layout, 328
  template laydowns, 92, 96, 103, 109
  washrooms, 320
  work stations, 44, 166
Plant layout plans, activities affected by, 28, 31
  actual performance from, 135–140
  basic facts of, 25
  design of, 5, 6, 25
  development of data for, 2–5
  development of drawings for, 106, 107
  estimating output capacity for, 135–140
  normal life of, 127, 128
  objectives of, 124, 128, 129
  plot plans, 73, 74, 76, 77, 308, 358, 359
  potential savings from, 27
  preliminary survey for, 62–65
  selection of, 123–126
  statistics for, 62, 64, 65
  subdivisions of plant in, 172
  tentative drafts of, 64, 65, 67
  types of, 42, 60–62, 67, 90
Plant layout plot plans, *see* Plot plans
Plant layout procedures, 115, Fig. 53
Plant layout project, time to develop, 352
Plant layout scale models, *see* Scale models
Plant layout sketches, cross-sections of buildings, 333
  field sketches of floor plan, 85
  floor sketches for machine templates, 87
  locating machines by triangulation, 89
Plant layout templates, *see* Templates
Plant modernization, aluminum foil rolling mill, 50
  automobile body assembly, 50
  baking industry, 40, 41
  ceramics plant, 36
Plant modernization, foundry and machine shop, 125, 126, 358, 362, Fig. 212
  furniture factory, 329
  gauge rooms, 249–251
  gear-motor assembly, 32, 33
  in World War II, 184
  laboratories, 249–251
  laboratory buildings, 332
  mechanization of handling, 184
  molding and casting in a foundry, 112
  need for, 321
  oil refinery expansion, 68, 70, 91
  prime objectives of, 38
  printing plant, 323–325
  refractories plant, 198
  shapes of buildings, 331
  turbine manufacturing, 51
Plant output, breakdown by products, 137–139
  in total U. S., 56, 57, 338, 344
Plant shortage in U. S., 345, 346
Plant site, boundaries of, Fig. 55
  data required on, 325
  layout of, 117
  restrictions from, 323, 324
  selection of, 324
Plants, design of, 29, 30, 58, 325–328, 330–333
  number of, in U. S., 56
  output of, in U. S., 56, 57, 338, 344
  pilot, 58
  size pattern of, in U. S., 55–57
  types of, 25
  wage earners in, 55, 56
Platform for loading, 215–220
Plot plans for plant layout, electronics plant, 308
  for proposed additions, 357, 358
  in three dimensions, 359
  of modern manufacturing plant, 72–77
Pneumatic systems, classification of, 188, 189
Power, single-line wiring for, 278, 279
  load-center distribution of, 280, 281
Power distribution, electric, 277
  load center for, 280, 281
Power drives, capacity of, 284, 285
  characteristics of, 283, 284
  group motor drives, 284–286
  individual motor drives, 283–285
  layout of, 285, 286
  mounting of, 285, 286
  types of, 282
Power feeders, locating of, 281
Power load, estimating of, 280
Power plants, 272–275
Power substations, 280–281

Power system, components of, 276
Power transmission, 282–285
Pratt and Whitney Aircraft Corp., 207, 216, 292
Presentation of plant layout proposal, 351
President's office, specimen of, 295
Private offices, layout of, 295, 296, 300–302
Process flow charts, advantages of, 8
  construction of, 163
  data summarized on, 64
  for a capacitor, 79
  for a cylinder head, 159
  for a 750-watt lamp, 160
  for a 60-watt lamp, 121
  purpose of, 158
  symbols for, 158
  types of, 158, 162
  ultimate use of, 162
Process handling equipment, classification of, 188, 189
Processes, technical knowledge of, 149
Processing departments, boundaries of, 49
  signs of improper layout in, 36, 37
Product cost, *see* Cost of product
Product design, basis for product analysis, 4
  changes in, 193
  manufacturing factors of, 131
  probable duration of, 127, 131, 134
Product load analysis form, 131, 141, 144
Production center, output capacity of, 173
Production control, benefits from layout, 34
Production cost, *see* Cost of Manufacturing
Production data for plant layout, 68, 116, 117, Fig. 53
Production Engineering and Management, 92
Production facilities, data on, 80–84, 118–120, Fig. 53
Production flow charts, *see* Process flow charts
Production in straight-line flow, 42, 213
Production increase, 9
Production line, advent of, 49
  description of, 172
  functional type of, 43, 51, 55
  inspection station on, 252
  straight-line type of, 42, 213
Production load, check-list of, 68
Production per plant in U. S., 56, 57
Production quantity requirements, 134
Production trends and forecasts, 61
Production volume, by components, 142
  by products, 137–139
  seasonal influences on, 146
Project engineer, duties of, 17
Project proposal, evaluation of, 359, 363
  for capital outlay, 350
Proving grounds, 253
Pure Oil Co., 304
Pyramid Mouldings, Inc., 213

Quality control, conditions required for, 245
  in receiving department, 247
  layout for, 252, 253
  necessity for, 244
  operation factors of, 157
  planning for, 246, 247
  preventive measures for, 246
  provisions for, 245, 246
  quarantine area, 247, 248
  test floor for, 254
Quarantine area for production control, 247, 248

Racks for storage, 239–242
Railcar dimensions, 218, 219
Railroad data for layouts, 219
Railroad equipment for material handling, 186, 187
Ramps, overhead, 308
Rate-setting, methods of, 168, 169
Raw materials, market conditions of, 235
  operation factors of, 157
  selection of, 156, 157
Raw stores, 232
Receiving department, design of, 214, 215
  layout of, 246–249
  signs of improper layout in, 35
Receiving facilities, 223, 226
Receiving material, 200, 211, 212
Reductions in cost, *see headings beginning* Savings
Rehabilitation, in post-war period, 345
  of a plant, 322
Renderings by architects, 225, 353
Repair shops, types of, 259
Republic Steel Corp., 327
Reserve stock, 232
Rest rooms, 320
Right-angle stacking, 204
Roof standards for one-story plants, 333, 334
Roofs, types of, 227
Routing of operations, 130

Safety standards, 203
Sales forecast by products, 144, 145
Sales requirements, 67
Savings, in direct labor cost of material handling, 180
  in labor cost from plant layout, 31, 34, 140, 144

Savings, in manufacturing cost, from plant layout, 34, 35, 148, 321
  opportunity for, 10
Savings potentials in material handling cost, 26, 27
Savings returns on expenditures, 366, 368
Sawtooth roof, 333, 334
Scale models, advent of, 94, 101, 102
  ASME standards for, 99–101
  in developing a layout, 105–108
  layouts planned with, 102–107, 112, 355
  miniature plants from, *see* Miniature plants
  used with templates, 103
  wooden versus cast metal, 102
Scrap disposal of metal chips, 207
Seasonal influence on output, 146
Selection, of building, 328, 331, 353
  of machinery, 156
  of manufacturing methods, 154–156
  of material-handling equipment, 195, 207
  of operations, 168
  of plant layout plan, 123–126, 132, 148
  of raw materials, 156, 157
Sequence of operations, 120, 158
Service departments, maintenance of, 261
  boundaries of, 49
Serving counter in cafeteria, 315
Shelving clearances in offices, 299
Shipping department layout correctives, 35
Shipping dock with overhead doors, 216
Shipping facilities, planning of, 223, 226
Shipping material, 211, 212, 232
Shipping port, 221
Shop offices, 296
Siding, freight-car, 201, 337
Sinclair Refining Co., 332
Singer Manufacturing Co., 335
Single-line wiring, 278, 279
Site, *see* Plant site
Sketches, *see* Plant layout sketches
Skids in warehouses, 192, 200
Slater, Samuel, 23
Sloane-Blabon Corp., 327
Small-lot orders, 145
Society for Industrial Packaging, 205
Soil-bearing value, 325, 326
Southern Railway System, 331
Spans in factories, 335
Spotting machinery on layouts, 88, 89
Sprinkler systems, operation of, 267, 268
  types of, 268, 269
Stacking, diagonal, 204
  right-angle, 204
Stacking storage, 200
Standard Register Co., 324, 325
Standard time operation routing form, 130
Standpipe water system, 270
Steam requirements, 271, 272
Stevenson, Jordan & Harrison, Inc., 303
Stock orders, 145
Stock piles, 232
Stock rooms, 232
Stone & Webster Engineering Corp., 51, 272, 276, 304, 314, 320, 328, 359
Storage, hauling to, 200
Storage, bins, 231–234, 241
  facilities, classification of, 188, 189
  in dispatch stations, 255–257
  in work stations, 173, 174, 239, 240
  of containers, 199
  of hot water, 273
  of work in process, 236
  on floor, 242
  on production line, 251
  outside, 237, 238
  racks, 239–242
  requirements, 234–236
  space, 227
Storerooms, capacity of, 235, 236
  design of, 237
  for material, 232
  functions of, 231, 232
  location of, 237
  of yesteryear, 230
  planning of, 230, 231
  requirements of, 232, 233
  signs of improper layout in, 35
Stores issues, 234
Straight-line production, actual layout of, 50–54
  arrangement of machinery in, 49, 50
  description of, 42
  flow of material in, 213
Supervision in factory, layout savings in, 34
Supply room, 232
Survey of markets, 4
Switchgear equipment, location of, 281, 282

Tabulating room, 293
Template laydowns, 90–93, 103
Template layouts, 123, Fig. 53
Template sheets for machinery and equipment, 90, 91
Templates, ASME standards for, 98, 99
  block, 94, 95
  field sketches for, 86–88
  in developing a layout, 105–108
  model combinations with, 93, 103, 104

Templates, on complete layouts, 52–54, 96, 109
  on machine reference cards, 81
  on work-station layouts, 44
  shuffling of, on floor plan, 164
  types of, 94, 95
Test floor as proving grounds, 253
Test floors, layout of, 254
Thompson Aircraft Products, Inc., 310
Tiering machines, classification of, 186, 187
  types of, 192
Tiering operations, 228
Time clocks, 311
Time studies, functions of, 168
  observations made in, 168
Time study espousal of plant layout, 24
Time values, decimal hours for, 153
  estimated by foremen, 169
  in layout work, 152, 153
  Labor Costimator chart, 154, Fig. 69
  of past performance, 169
  standard indexed data of, 170
Tonnage handled, 177, 178
Tool cribs, centralization of, 263, 264, 266, 267
  chains systems of, 263, 264, 267
  layout of, 263
  planning of, 264, 265
  stores functions of, 232
Tool Engineer, The, 213
Tool maintenance, 266
Tool reconditioning, 265–267
Tooling, operation factors of, 157
Tools, design of, 193
Tractor-and-trailer trains, types of, 190
Tractors, classification of, 186, 187
Traffic hazards, 201
Traffic in aisles, 202
Trailers, classification of, 186, 187
Transformer equipment, location of, 280, 281
Transportation, air-freight, 222
Truck dimensions, 217
Truck ports, 214
Trucks, classification of, 186, 187
  lift types of, 192
Turbines, exhaust-steam, 273

Unit loads, in a glass factory, 220
  planning of, on pallets, 202
  racks for, 129
  storage of, on pallets, 238
U. S. Dept. of Commerce, 200, 203, 204
U. S. Gypsum Co., 291, 305, 306
U. S. Rubber Co., 315
Utah Oil Co., 70, 71

Vending machines, 319
Voltage, choice of, 282

Wage earners per plant in U. S., 55, 56
Wage rates, ceiling on, 10
Walkway, overhead, 310
Warehouses, basic types of, 228, 229
  handlings of material in, 227
  skids and pallets in, 200
Wartime expansion, 344–348
Wartime production, 184
Wash fountains, 319, 320
Wash rooms, 319, 320
Water supply, sources of, 269, 270
Water tanks, gravity, 269
Water towers, 269, 270
Westinghouse Electric Corp., 47, 52–54, 72, 73, 96, 103, 111, 112, 121, 160, 190, 248, 250, 252, 254, 256, 257, 354
Window-sill heights in offices, 298
Work center, at assembly station, 46, 47
  at work station, 43, 44, 47, 48
  in machine crew, 45–48
  in process industries, 45, 46
  subdivision of layout, 172
Work elements, non-productive, 8
Work in process, movement of, 254, 255
  storage of, 232
Work sheet for operation and process flow charts, 161
Work simplification techniques, 197
Work station, advantages of planning of, 171
  as work center, 43, 44, 47, 48
  auxiliary equipment needed in, 164, 165
  boundaries of, 165
  definition of, 165
  floor area in, 43, 45
  layout form for, 119, 132, 166
  layout of, 44, 165, 166
  material handling in, 171, 173
  output capacity of, 173
  storage of material in, 173, 174, 239, 240
  workbenches in, 174–176
Workbenches, conveyorized, 260
Workbenches at work stations, 174–176
Workers, benefits from good layout, 31
  operation factors of, 157
  signs of improper layout on, 37
Working conditions, 307
Wrigley, Wm., Jr., Co., 291

Yard hydrants, 269
Yard storage, 232, 237, 238